SECTION 1—MEANS OF DELIVERY TECHNOLOGY

Scope

Highlights

- Several means are available to deliver WMD: ballistic missiles, cruise missiles, aircraft, and artillery.
- The delivery means a nation uses depends on the availability of the vehicle, the survivability of the delivery system, the nature of the target, and the objective.
- Optimum effectiveness might not be the driving factor when selecting a means of delivery.
- Aircraft generally carry more payload weight than ballistic or cruise missiles.
- Ballistic missiles which are mobile are less vulnerable than fixed sites to U.S. offensive operations.
- Modern cruise missiles are generally more accurate and less expensive than ballistic missiles.

BACKGROUND

The means that a nation uses to deliver a weapon of mass destruction (WMD) depends in part on the availability of a vehicle, the survivability of the delivery system, the characteristics of its intended target, and the nation's military objective (even if the target is civilian in nature). These factors are not mutually exclusive considerations. Many proliferants have demonstrated clever methods to adapt one delivery vehicle, which it can easily acquire, to other applications much different from the original purpose of the vehicle. Similarly, some nations have launched effective attacks against targets that U.S. analysts might initially overlook because of a different perception of the importance of these targets.

When a proliferant has invested both the expense and talent to develop a WMD arsenal and the means to deliver it, it does so to be capable of launching a sufficiently effective attack. Consequently, the means of WMD delivery a proliferant selects usually reflects some planning and coordination of its objectives. No strategist can completely rule out an irrational or desperate WMD attack from a proliferant. However, such attacks, *because* of their very irrationality, will generally not inflict the damage necessary to change the course of a conflict. Nor is the threat of an ineffective and irrational attack likely to serve the goal of deterrence or further the change that a proliferant might pursue.

With these restrictions in mind, a nation will select a means of delivery that furthers its goals. This does not mean that the proliferant must seek ways to *optimize* the effectiveness of a WMD attack, as nations with modernized militaries do. Proliferants might conduct an attack merely to demonstrate an intention or a capability. Certain characteristics of delivery systems and the types of WMD they carry are naturally associated with these goals.

Delivery Systems Considerations for Chemical or Biological Payloads

To be truly effective, chemical or biological agents must be spread in a diffuse cloud over a large area. Certainly, any chemical or biological cloud may find some victims, but highly concentrated clouds spread over very small areas or pools of agent puddled on the ground have limited effectiveness because they come into contact with only a small portion of the targeted population or equipment.

Meteorological conditions affect the size and concentration of a windborne agent cloud and its durability. Hence, the interaction of the delivery vehicle and the local meteorology is an important consideration when a proliferant contemplates a chemical or biological attack. Some of these conditions even affect the probability that the cloud will reach its target after it has been released from a delivery vehicle. The United States' experience in testing windborne agents has shown that a cloud must be released below an atmospheric shear layer or it will disperse before reaching the ground. Most shear layers occur at around 500 feet above ground level (AGL).

Shifting wind conditions, local topography and micro-meteorology, and the presence of manmade structures also affect the distribution of the agent within the cloud and its dissemination from a delivery vehicle. Biological agents, in particular, decay rapidly in the presence of strong sunlight and quickly become ineffective. Some chemical agents also suffer from degradation in sunlight and from interaction with water vapor and other constituents of the atmosphere. Winds channeled by tall buildings and geographic features may deposit some of the cloud in unexpected locations. Delivery vehicles themselves create a disturbance in the wind field because of the aerodynamic and propulsive effects generated by the vehicle. Since some of these conditions change over the course of hours, an attack that is launched at a particularly propitious time under the local meteorological conditions at the target may not be effective by the time the WMD arrives. With sufficient warning of a chemical and biological weapon attack, a population can take protective measures that may be quite effective.

To be effective, a delivery vehicle employed to spread chemical or biological agents must distribute the material in a fine cloud below a certain altitude and above the surface. It should be capable of all-weather operations and should not betray its presence to air defense assets. These traits are considerations that will determine the overall effectiveness of a chemical or biological attack. Proliferants with limited military budgets must also consider the cost of acquiring and maintaining a WMD delivery system arsenal as well as the warheads. This may limit a proliferant to developing or purchasing only one or two types of delivery systems rather than simultaneously pursuing multiple systems.

Delivery systems vary in their flight profile, speed of delivery, mission flexibility, autonomy, and detectability. Each of these considerations is important when planning a chemical or biological attack.

Ballistic missiles have a prescribed course that cannot be altered after the missile has burned its fuel, unless a warhead maneuvers independently of the missile or some form of terminal guidance is provided. A pure ballistic trajectory limits the effectiveness of a chemical or biological attack because, generally, the reentry speed is so high that it is difficult to distribute the agent in a diffuse cloud or with sufficient precision to ensure a release under the shear layer of the atmosphere. In addition, thermal heating upon reentry, or during release, may degrade the quality of the chemical or biological agent. U.S. experience has shown that often less than 5 percent of a chemical or biological agent remains potent after flight and release from a ballistic missile without appropriate heat shielding.

A ballistic missile also closely follows a pre-established azimuth from launch point to target. The high speed of the ballistic missile makes it difficult to deviate too far from this azimuth, even when submunitions or other dispensed bomblets are ejected from the missile during reentry. Consequently, if the target footprint axis is not roughly aligned with the flight azimuth, only a small portion of the target is effectively covered.

A ballistic missile has a relatively short flight time, and defenses against a ballistic missile attack are still less than completely effective, as proved in the Allied experience during the Gulf War. However, with sufficient warning, civil defense measures can be implemented in time to protect civil populations against chemical or biological attack. People in Tel Aviv and Riyadh received enough warning of SCUD missile attacks to don gas masks and seek shelter indoors before the missiles arrived. Even with these limitations on ballistic missile delivery of airborne agents, Iraq had built chemical warheads for its SCUDs, according to United Nations’ inspection reports.

Cruise missiles, in contrast, can be guided and follow almost any course over the ground that a mission requires. The speed of a cruise missile is compatible with an effective dissemination of both chemical and biological agents, although designers generally must plan to release these agents outside of the aerodynamically disturbed flow field around the vehicle. If the cruise missile is outfitted with a sensor platform, it may determine the local meteorological conditions and alter its flight profile appropriately before it releases the agent. Unmanned air vehicles (UAVs) are naturally more difficult to detect because of their small size and ability to fly below radar horizons. On the other hand, their slow speed increases their vulnerability to defenses.

Most nations that manufacture chemical and biological agents produce these agents in large quantities. The delivery system costs can become the ultimate limiting factor. Since cruise missiles are much less expensive than either manned aircraft or ballistic missiles, a proliferant can overcome the liabilities of delivery cost efficiency by selecting suitable cruise missile systems.

Manned tactical aircraft and bombers have several of the advantages of cruise missiles, but some additional liabilities. Manned aircraft are expensive to maintain. They also require routine flight operations for crew training, expensive upkeep programs, hangars for housing, and large air bases for basing. If an airplane is lost or shot down, the loss of the pilot complicates subsequent attack planning. Unless a nation has acquired highly capable aircraft or retrofitted its existing aircraft with advanced technology, there may be limitations to all-weather or night operations. Since biological attacks are most effective at night when there is no sunlight to decay the agent and the atmosphere is settling towards the ground as it cools, a limitation on night operations characteristically limits the effectiveness of some biological attacks. The flexibility of flight planning and attack strategy, however, weighs in favor of manned aircraft. A pilot is able to change targets if the battle situation dictates.

Delivery System Considerations for Nuclear Payloads

Nuclear weapons differ markedly from chemical, biological, or conventional warheads. The principal difference is the size, shape, and inertial properties of the warhead. Generally, nuclear weapons have a lower limit on their weight and diameter, which determines characteristics of the delivery system, such as its fuselage girth. Though these limits may be small, geometric considerations often influence the selection of a delivery system. Chemical and biological weapons, which are usually fluids or dry powders, can be packed into almost any available volume. Nuclear weapons cannot be retrofitted to fit the available space; however, they can be designed to fit into a variety of munitions (e.g., artillery shells).

Nuclear weapons also have a different distribution of weight within the volume they occupy. Fissile material, the core of a nuclear weapon, weighs more per unit of volume than most other materials. This high specific gravity tends to concentrate weight at certain points in the flight vehicle. Since virtually all WMD delivery systems must fly through the atmosphere during a portion of their trip to a target, a designer has to consider the aerodynamic balance of the vehicle and the required size of control system to maintain a stable flight profile while carrying these concentrations of weight. Chemical, biological, and conventional weapons all have specific gravities near 1.0 gram/cc, so these materials may be placed further from the center of gravity of the vehicle without providing large compensating control forces and moments. In some special applications, such as ballistic missile reentry vehicles and artillery shells, the designer needs to include ballasting material—essentially useless weight—to balance the inertial forces and moments of the nuclear payload.

Because nuclear weapons have a large kill radius against soft and unhardened targets, accuracy is a minor consideration in the delivery system selection as long as the targeting strategy calls for countervalue attacks. Nuclear weapons destroy people and the infrastructure they occupy. They only require that the delivery system places the warhead with an accuracy of approximately 3 kilometers of a target if the weapon has a yield of 20 kilotons and to an even larger radius as the yield grows. Most unmanned delivery systems with a range of less than 500 kilometers easily meet these criteria. Often, as is the case with ballistic missiles, the quality of the control system beyond a certain performance does not materially change the accuracy of a nuclear warhead, because a large fraction of the error arises after the powered phase of the flight as the vehicle reenters the atmosphere. While this is true of chemical and biological warheads as well, with a nuclear warhead, there is less need to compensate for this error with such technologies as terminal guidance or homing reentry vehicles.

A proliferant most likely would not manufacture or obtain nuclear weapons in the same quantities as chemical, biological, or conventional weapons. This may cause a proliferant to place more emphasis on the reliability of the vehicle and the targeting methods it selects to deliver nuclear weapons. Reliability may refer to the delivery system or its ability to penetrate defenses to deliver a weapons load.

Many factors contribute to the ability to penetrate defenses, including the proximity of approach before detection, the velocity of the delivery system, and the time to target after detection. Cruise missiles approach much closer to a target before being detected, but their slow speed also means that the defense has time and capabilities to intercept them in a realistic manner once they are detected. Ballistic missiles can be detected upon launch, but their high reentry speed still makes them difficult targets to acquire and intercept before they reach the target. A proliferant nation must weigh these considerations along with the availability of technologies for building certain delivery systems when it develops a targeting strategy for its nuclear weapons. If a defending country can alert its population of an impending attack, a ballistic missile launch detection system provides about 8 minutes of warning for a missile with a 500-km range. Alternatively, the population has 5 seconds of warning for every mile from the target that a transonic cruise missile can be detected. If the defending nation can detect the cruise missile 100 miles from the intended target, it has about 8 minutes to intercept the missile.

From the standpoint of defense, stealthy cruise missiles pose the greatest threat as a delivery system, regardless of the WMD type. Manned aircraft, while a serious threat, have other limitations, such as their unrefueled range, their capability or lack of capability to operate in all weather conditions and at day or night, their visibility to defense detectors, and their high acquisition, maintenance, and training costs.

OVERVIEW

Proliferants that are acquiring WMD have an array of vehicles available to deliver their payloads. The "Means of Delivery" section covers the primary *military* methods of delivering WMD. The section focuses on unique aspects of these delivery systems and simple modifications to them that enhance the ability of a proliferant to conduct a WMD attack. Excluded from this topic are adaptations of civilian vehicles, such as automobiles or small boats, which usually accompany terrorist acts. Furthermore, the discussion generally considers only the primary delivery means to carry a weapon to its final target. Except for aircraft carrying WMD bombs or glide devices that steer or fly toward a target after being dropped, the discussion does not treat secondary vehicles that move WMD closer to a target before launch. These vehicles, which include submarines and surface ships carrying ballistic or cruise missiles on board, have such broad military applications that their acquisition cannot be uniquely associated with WMD.

This section will first list the conditions for effective delivery of a payload and then its associated influences on the choice of a delivery system. Each of the subsections that follow emphasizes and elaborates upon certain technologies that a proliferant might use to make its delivery system more effective.

RATIONALE

The ability to produce any of the three types of WMD does not give a proliferant operational capability in that type of weapon. The weapon must be integrated with a delivery system to get the weapon to the intended target. Military systems have been included in this section because they are of most concern. Civilian vehicles (e.g., boats, aircraft, trucks) are not covered because they are so common throughout the world. Yet, they could also be used to deliver a WMD or other significant weapons to a particular location, as was demonstrated in the Saudi Arabia bombing in which a commercial truck was used.

Some ballistic missiles have been purchased (and possibly modified for longer range), and others have been developed indigenously. Although intercontinental ballistic missiles (ICBMs) are not widespread, proliferants might obtain the technology to produce them. Cruise missiles provide WMD delivery capability with relatively low technology and ease of acquisition. Most militaries have combat aircraft or the means to purchase them. As long as a nuclear, biological, or chemical weapon can be developed to be carried on an aircraft and successfully released, it is a threat that needs to be considered.

Artillery is common in the world's armies and can also be used to deliver a WMD. There are many kinds of artillery with varying capability. Nuclear, chemical, and biological munitions that are usable by many existing artillery systems have been produced. The technology has been available for many years and is quite well understood. Also included in the Artillery subsection is the Multiple Launch Rocket System (MLRS).

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 1.0-1)

Over two-thirds of the countries that cause concern have programs to acquire ballistic missiles. Even though short-range anti-ship cruise missiles are widely available, only a few countries possess long-range land-attack cruise missiles. With the success of long-range cruise missiles in Desert Storm and its aftermath, indigenous development programs can be expected among proliferants. Combat aircraft are already available in every country that has or is suspected of acquiring WMD, and many are being modernized. All armies have artillery that could be adapted to deliver WMD.

Country	Sec 1.1 Theater Ballistic Missiles	Sec 1.2 ICBMs	Sec 1.3 Cruise Missiles	Sec 1.4 Combat Fixed-Wing Aircraft	Sec 1.5 Artillery
Argentina	♦♦	♦♦	♦♦	♦♦	♦♦♦
Brazil	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦
Canada	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Chile	♦	♦	♦	♦	♦♦♦
China	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Egypt	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦
France	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Germany	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
India	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦
Iran	♦♦	♦	♦♦	♦♦	♦♦♦
Iraq	♦♦	♦	♦♦	♦♦	♦♦♦
Israel	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Italy	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Japan	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Libya	♦	♦	♦	♦	♦♦♦
North Korea	♦♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦
Pakistan	♦♦	♦♦	♦♦	♦♦	♦♦♦
Russia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
South Africa	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦
South Korea	♦♦	♦♦	♦♦	♦♦	♦♦♦♦
Sweden	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Syria	♦♦	♦	♦	♦	♦♦♦
Taiwan	♦♦♦	♦♦	♦♦♦	♦♦	♦♦♦♦
Ukraine	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United Kingdom	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United States	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦

Legend: Sufficient Technologies Capabilities: ♦♦♦♦ exceeds sufficient level ♦♦♦ sufficient level ♦♦ some ♦ limited

Because two or more countries have the same number of diamonds does not mean that their capabilities are the same. An absence of diamonds in countries of concern may indicate an absence of information, not of capability. The absence of a country from this list may indicate an absence of information, not capability.

Notes: Each delivery system column reflects the technologies listed in greater detail in the section describing that delivery system.

The technology columns listed in the Foreign Technology Sections on the individual delivery systems refer to technologies that one or more of the listed countries may need. Lack of capability in one technology does not indicate a country has limited capability. It may indicate the country is pursuing a different technology solution.

Figure 1.0-1. Means of Delivery Foreign Technology Assessment Summary

SECTION 1.1—THEATER BALLISTIC MISSILES (TBMs)

OVERVIEW

The Theater Ballistic Missiles (TBMs) subsection describes the technologies that a nation can employ to build a TBM and the associated means by which they can use it. The U.S. Government defines a TBM as a ballistic missile with a range of less than 3,500 km. Except where noted, this document will use that definition. This subsection emphasizes those technologies that improve accuracy, reduce intercept at boost, increase lethality, and assist a country in extending the range of its missiles, transporting and launching the missiles clandestinely, and building them in sufficient numbers to achieve its objectives. The tables tabulate technologies or their adaptation to entire missiles and their subsystems. They are ordered as follows: *airframe; propulsion; guidance, control, and navigation*; and *weapons integration*.

When a proliferant seeks a range extension from an existing airframe, it may need to strengthen the airframe if the original missile had a low factor of safety. This is necessary so the missile can withstand higher aerodynamic loads; change the *propulsion* subsystem by altering either the burning rate or the duration of propellant flow or by selecting a high-energy propellant; adapt the *guidance* system to accommodate the new acceleration loads and the higher cutoff velocities; and *weaponize* the warhead by including thermal protection on the nosetip or modifying the reentry strategy of the missile to withstand the higher aerodynamic heating on reentry.

Proliferants can modify or manufacture longer range ballistic missile airframes in several ways. Iraq extended its missile range by reducing the payload and lengthening existing airframes to hold more fuel and oxidizer. Iraq also introduced the concept of "strap-ons" to extend a missile's range when it launched the "al Abid" in December 1990. To manufacture the "al Abid" missile, Iraq strapped five SCUDs together to form a single large missile, theoretically capable of a 2,200-km range.

Proliferants can also stage missiles in parallel or serial. The United States used a concept known as "parallel staging" to extend the range of its Atlas missile. Parallel staging fires several component engines simultaneously at launch. Then, as the missile accelerates, it drops these extra engines. When a nation possesses the technical capability to support extra range, the most efficient way to achieve it is through conventional "serial" staging, in which a missile's stages fire one at a time in sequence. Some Chinese TBMs, such as the M-11, which may have originally been designed as a multiple-stage missile (and, therefore, has sufficient thrust-to-weight ratio), can be converted to two-stage missiles with minor modifications and modest assistance from technical experts if they are aware of certain design limitations.

Highlights

- Chemical and biological weapons are difficult to dispense efficiently from TBMs.
- Proliferants with just a few nuclear weapons may consider TBM reliability before using this means of delivery.
- Separating warheads increase the probability of defense penetration.
- Attitude control modules and post-boost vehicles increase TBM warhead accuracy.

But some constraints, such as avoiding maximum dynamic pressure at staging and timing the staging event precisely enough to maintain control over the missile, are solved when multi-stage missiles are built derived from components which originally came from a multi-stage missile.

To extend the range of liquid-fueled and solid-fueled missiles, these missiles require different adaptations to the *propulsion* subsystem. Liquid-fueled missiles supply fuel to the thrust chamber by turbopumps. To increase the range of an existing liquid-fueled missile, the proliferant must either increase the flow rate of the propellant and oxidizer or allow the missile to burn for a longer period of time. This can be accomplished by adding more propellant, which usually requires a modification to the airframe, and consideration of other factors such as structural integrity, stability, and thermal integrity. If a longer burn time is chosen, many surfaces that are exposed to the combustion process, such as jet vanes in the exhaust flow or components of the thrust chamber, may need to be modified to protect them from the increased thermal exposure. Alternatively, if the missile thrust is to be increased, the combustion chamber must be designed or modified to withstand the increased pressures, or the nozzle must be redesigned with a larger throat area to accommodate the increased mass flow rates. In addition, structural modifications may be required to compensate for the higher aerodynamic loads and torques and for the different flight profile that will be required to place the warhead on the proper ballistic phase trajectory. Usually a country will design a completely new missile if new turbopumps are available. A proliferant that wishes to increase its liquid-fueled missile's range may need to consider upgrading all the valving and associated fluidic lines to support higher flow rates. The proliferant will seek lightweight valves and gauges that operate with sub-millisecond time cycles and have a reliable and reproducible operation time. These valves must also accept electrical signals from standard computer interfaces and require little if any ancillary electrical equipment. A country may use higher energy propellant combinations in existing missile designs with relatively minor structural, material, and turbopump modifications. Technology requirements would focus on thermal protection for the thrust chamber and improved injector design.

A solid-propellant missile differs in overall operation because it simply burns propellant from an integral motor chamber. A proliferant seeking to make longer range solid missiles generally has to stage the missile (either in parallel or serial); strap on additional whole motors or motor segments; improve the stage fraction; or improve the propellant. When a nation chooses to stage an existing missile, it may be able to procure the first stage of a serially staged design, which is larger and more difficult to manufacture, and simply add an indigenous smaller upper stage of its own. A key determinant of a missile's utility as a first stage is the performance specification of thrust-to-weight ratio. Whole missile systems used as a first stage must produce a thrust-to-weight ratio greater than one for the entire assembled multi-stage missile. Missiles that may fall below the Missile Technology Control Regime (MTCR) guidelines are still of interest because they might be used by proliferants as upper stages of serial staged missiles or as strap-ons.

Once a country can indigenously produce a solid rocket motor, few, if any, components do not automatically scale from more basic designs. If a proliferant desires a more advanced solid rocket fleet, it may choose to build the missile case from carbon graphite or more advanced organic matrix materials. To support this, it will need to import either filament winding machines, an equivalent manufacturing process, or the finished motor cases. A proliferant might import the finished filament wound cases without propellant if it chooses to use a manufacturing technique pioneered in the former Soviet Union known as "cartridge loading." Cartridge loading allows the propellant to be inserted into the case after it is manufactured. The competing manufacturing procedure, known as "case bonding," usually requires the case, propellant, and insulating liner to be assembled in close proximity at the same site, though it is still possible to import empty cases for case bonding. Designs employing propellants with higher burning temperatures require many supporting components, including better insulating material to line the inside of the rocket case and stronger or larger thrust vector control actuators to direct the increased thrust.

The three separate flight functions performed by the *guidance, control, and navigation* subsystem generally require separate technical considerations. Guidance refers to the process of determining a course to a target and maintaining that course by measuring position and attitude as the missile flies (while, at the same time, steering the missile along the course). Control generally encompasses the hardware and software used during the missile's burn phase to change the missile's attitude and course in response to guidance inputs and to maintain the missile in a stable attitude. Navigation concerns locating a target and launch point and the path that connects them in three-dimensional space. An effective design requires that all three functions operate in concert before and during flight for the missile to reach its target. Some of the hardware and software in each feature overlaps functions.

The aerodynamic and inertial properties of the missile and the nature of the atmospheric conditions through which it flies determine the speed with which guidance commands need to be sent to the control system. First generation TBMs, such as the SCUD and the Redstone, have fins to damp out in-flight perturbations. The rudimentary guidance systems used in these missiles do not support rapid calculations of position changes. When a missile's thrust vector control system becomes responsive enough to overcome these perturbations without aerodynamic control surfaces, these fins are usually removed from the design because their added weight and aerodynamic drag diminish the missile's range.

Most TBM designs have a resonance around 10 Hz (cycle time of 100 milliseconds). Calculations to correct disturbances must occur within this cycle time. Guidance and control engineers generally add a factor of safety of two to their cycle time or, in other words, half the cycle time. When thrust vectoring is the exclusive control standard of a missile, the system must respond or have a major cycle time of 50 milliseconds or less. When fins are used, the control cycle time for a missile may be much longer than a second.

As the guidance and control subsystems work together to keep a missile stable and flying on its trajectory, all the components of these subsystems must operate within the major cycle time. Guidance computers, for instance, have to accept acceleration, angular position, and position rate measurements; determine if these positions are proper for the missile's course; and correct any deviations that have occurred in the flight profile. Computers of the i8086 class, and later, are capable of making these calculations in the times required. In addition to the calculation procedures, all the control hardware must reliably and repeatedly accept the control signals generated by the flight computer and effect the commands within the cycle time. Since some of these operations must occur in a specific sequence, the sum of all operational times in the sequence must be much shorter than the major cycle time. Therefore, valves, electric motors, and other actuators must produce steering forces within 50 milliseconds to support an unfinned ballistic missile control system. When the missile has fins, the allowable response times increase, permitting the hardware operational specifications to be greatly reduced.

In addition to the cycle time, the control subsystem must also hold the missile within acceptable physical deviations from specified attitude and velocity during its short burning period. Missiles with autonomous control systems generally rely on acceleration measurements rather than position measurements to determine attitude and position rates. However, positional indications can be substituted if the positional variables can be determined quickly and accurately enough. Position measurements reduce the control system cycle time by generally reducing the computer integration of accelerations that are required to determine position. Positional measurements also do not suffer the degradation in performance that occurs with time, acceleration force, and vibrations on measurement instrumentation that supports acceleration measurements.

Multi-source radio signals that allow a triangulation of position offer an alternative to acceleration measurements. Advanced missile powers dropped radio guidance in the 1960's and switched to autonomous inertial measuring units, which are carried onboard the missile. The United States considered radio guidance again in the late 1980's for mobile missiles but dropped the idea in favor of a Global Positioning System (GPS). Nonetheless, if a proliferant chose to build a radio guidance system, it could transmit signals from the launch site, or it may build an accurate transmitter array near the launch site to create the signals. Guidance engineers often refer to this latter technique as using pseudolites. However, radio command and control schemes, because of the immediate presence of a radio signal when the system is turned on, alert defenses that a missile launch is about to occur. However, performance for these systems degrades because of the rocket plume and radio noise. Also, these systems are very much subject to the effects of jamming or false signals.

A number of new techniques are available for adapting GPS signals and other supporting navigation and locations systems for high precision use. In addition to reengineering the stored software on a GPS processor, a nation which seeks to upgrade its GPS receivers from coarse/acquisition (C/A-code) levels of performance to precision (P-code) levels of performance may perform post-processing on the received signals themselves. Post processing assists in position location because a large source of error in a GPS signal is the uncertainty in ionospheric refraction as GPS signals pass through the ionosphere. When a receiver can remove this error from the signals the location uncertainty falls from approximately 20 meters to less than 2 meters.

The broadcast ionospheric model is available to all users and is not encrypted. It can accont for perhaps 50–75% of the ionospheric error, but cannot handle short-term changes in ionospheric conditions. Any other source of information about the ionosphere can be used to correct the time-of-transmission calculation embedded within the C/A-code signal and determine the amount this signal has been slowed from the vacuum speed of light by the charged particles in the ionosphere. One source of correction schemes can be based on differential GPS (DGPS) signals which do not pass throught he ionosphere. Even when a DGPS receiver is removed as much as 100 nautical miles from the receiver it can give an approximate estimate of the ionospheric state provided it is near enough to account for seasonal and diurnal effects.

Other schemes include building an approximate picture of electrical flux in the ionosphere by obtaining very accurate ephemeris of the satellite position and post calculating corrections from the expected versus received positions of a precisely located point.

While these schemes will not the same accuracy as the P-code itself, they can aproximate the performance or at least improve C/A-code by an order of magnitude. In order to make them useful in a ballistic missile, a nation may write a software routine that allows a launch authority to load ionosphere corrections in at the last moment. In the same way that other targeting data may be included to align the gryoscopes at the last moment before launch, the corrections could be fed into a processor which uses the raw C/A-code values and then corrects them before sending a guidance signal to the thrust vector controls or control surfaces. GPS has significant application for a theater ballistic missile outfitted with a post-boost vehicle (bus) or attitude control module that navigates a reentry vehicle to a more accurate trajectory.

Older, less-sophisticated guidance systems perform less navigation than modern TBMs. In the older TBMs, a launch crew sets the aximuth to the target at a mobile site and the control computer determines when the missile is traveling at the proper velocity and velocity attitude angle to achieve the desired range. These three properties, in addition to random winds at the target and errors that accrue in the guidance instruments, uniquely determine where the missiles land. Any technologies that allow a proliferant to position and target its missiles in the field quickly reduces the time defending forces have to target and destroy the missile. GPS allows a mobile launch crew to operate more quickly in the field when not launching the missile from a pre-surveyed launch site.

When no in-flight update of position is given, a crew must set a reasonably accurate azimuth before the missile is launched. To be consistent with the overall accuracy of an older missile, such as the SCUD, which has a non-separating warhead, the crew must strike an azimuth line within 1 milliradian of the actual azimuth to maintain a satisfactory cross range accuracy. With military grade GPS receivers of 1–3 meter accuracy, the launch crew must survey no further than 1 km from the actual launch point to support a 1-milliradian azimuth. Pseudolites or differential GPS will either reduce survey distance required or increase accuracy—whether using military or civilian GPS signals.

Any technologies that allow for the separation of a reentry vehicle after the boost phase assist the proliferator in two ways. First, a separating warhead is often more accurate than a warhead that reenters while still attached to the main missile body. Secondly, the separated warhead produces a much smaller radar cross section (RCS), thus making the warhead harder to locate.

Technologies that assist a country in separating its warheads and producing a clean aerodynamic shape for reentry include computer aerodynamic prediction routines, nosetip materials that can withstand higher aerodynamic heating, and space-qualified small missile motors that can steer out accumulated error. Hardware that assists in separating a warhead from a booster includes timing circuits, squibs, and other cutting charges, and if accuracy is an issue, an alignment mechanism. This mechanism might be as simple as aerodynamic fins that unfold upon reentry.

RATIONALE

TBMs can carry a conflict outside of the immediate theater of fighting and can usually penetrate to their targets. Iraq's limited capability missiles made an impact by tying up allied air assets on seek-and-destroy missions against mobile launchers and in the other steps taken to calm Israeli and Saudi populations. Extant whole *missile systems,* such as the SCUD and SS-21, can satisfy the targeting needs for many proliferators.

A proliferator's potential ability to upgrade existing, outmoded missiles (e.g., short-range SCUDs) is quite real. Much of the hardware and technology to support many of the modifications described in the Overview are readily available or can be produced indigenously. However**,** some of the hardware and technology (those requiring more advanced technology, special materials, and/or precise manufacturing) are not readily available and may require special design and production efforts by more advanced countries. A proliferator can achieve an understanding of the most efficient and cost-effective methods to extend the range of a missile by using finite element structural and fluid dynamic computer routines and automated codes to predict missile performance and aerodynamic properties. A proliferator can also test and validate the computer routines in wind tunnels and structural laboratories. Since these computer routines reduce the number of engineers needed to modify missiles, they are particularly key to reducing both the unit and system costs. Automated engineering computer routines are ranked at the same level of importance in the technology tables as hardware items.

The type of propulsion system selected also affects *launch strategy,* the second important proliferant capability. Liquid-propellant missiles generally create less of a military threat than solid-propellant missiles. Solid-propellant missiles are stable and storable and do not require fueling before launch, a time when the missile is particularly vulnerable because of its exposure. In addition, solid-fueled missiles have a shorter launch support train than liquid-fueled missiles. Fewer vehicles and less activity associated with the vehicles limits exploitation of acoustic, seismic, and other signatures.

The enormous progress made in guidance and navigation with the GPS, particularly in automated design with computer routines such as finite element codes and in materials science with the introduction of composite materials, has further reduced the design burden on proliferants seeking TBMs. Transferred to proliferant nations, these advances streamline the manufacturing processes, which accelerate and expand the potential for a missile arsenal.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 1.1-1)

Several countries purchased SCUDs up to the end of the Cold War, and many of these countries still have arsenals of varying size and threat. These countries include Afghanistan, Egypt, Iraq, Iran, Libya, Syria, and Yemen. The Soviets also sold Syria, Yemen, and possibly Libya, the shorter range SS-21 missile. Egypt, Iraq, Iran, and North Korea all display the manufacturing base and technical prowess to make range extension modifications similar to those that Iraq accomplished before the Gulf War.

In addition to these countries, several nations have built or attempted to build their own TBMs. An inherent capability to produce unique and totally indigenous missiles exists in these countries: Argentina, Brazil, India, Iran, Iraq, Israel, North Korea, Pakistan, South Africa, and Taiwan, and nearing production in Syria. Iran and Iraq must import the guidance and control systems of these missiles; however, beyond those constraints imposed on Iraq by UN sanctions, it has no limitations on its ability to produce 600-km range TBMs.

Systems

Both China and North Korea continue to sell missile technology and missile systems. Also, North Korea continues to sell missiles abroad. North Korea has offered the 1,000-km-range No Dong missile, and the Chinese sold between 30 and 50 CSS-2's, a 2,200-km-range missile, to Saudi Arabia in the late 1980's. Apparently, the Israeli government acted as an intermediary for shipping Lance missiles to the Taiwanese. Lances are a short-range nuclear delivery system that the United States based in Europe. They can be reverse engineered to serve as strap-ons for existing missiles.

Each TBM may cost as little as $1.5 million dollars, so a proliferator with even modest resources can afford to build a sizable missile force. If a country seeks autonomy from the world market and wishes to build its missile indigenously, it can purchase a manufacturing plant from the North Koreans or Chinese for about $200 million and purchase critical parts, such as guidance systems, elsewhere. To develop complete autonomy requires a capital investment of about $1 billion dollars.

Technical Assistance

Besides whole systems, many corporations and nations have offered technical assistance during the last 10 years to some emerging missile powers. German firms reportedly assisted the missile programs of Argentina, Brazil, Egypt, India, Iraq, and Libya. Italians have offered assistance to Argentina, Egypt, and India, and the French have participated in missile programs in Iraq and Pakistan.

Most European countries can lend technical assistance to emerging missile powers. The French have a long history of developing missiles not only to support the Ariane space launch capability but to launch the *force de frappe* nuclear arsenal. The Italians have participated in the European Union space program that helped design and prototype the *Hermes* missile. While the British relied on American missile programs to supply their TBM needs in the 1960's, a technical exchange program between Britain and the United States has trained and educated a sizable pool of missile talent from the British Isles. Many Western European nations and Russia are in the process of downsizing their defense industries. As many as 2 million physicists and engineers may become available over the course of the next decade.

Country	Airframe		Propulsion			Guidance and Control			Weapons Integration		
	Airframe Extension to Liquid-Fueled Missiles	Post-Boost Vehicles	High Energy Solid-Fuel Motors	Storable Liquid Propellant Engines	Strap-on Boosters	Floated Inertial Measure-ment Units	Digital Navigation and Control	Post-Boost Position Realign-ment and Spin	Bomblets or Submun-itions	TEL Manufac-turing	Separating Warheads
Argentina	♦♦♦	♦	♦♦♦	♦♦	♦♦♦	♦♦	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦
Brazil	♦♦♦♦	♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦
Canada	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Chile	♦♦	♦	♦♦	♦♦	♦♦	♦	♦	♦	♦	♦♦♦	♦♦
China	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Egypt	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦	♦♦	♦♦♦♦	♦♦♦
France	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Germany	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
India	♦♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦♦
Iran	♦♦♦	♦	♦♦	♦♦♦	♦♦	♦	♦♦	♦	♦	♦♦	♦♦
Iraq	♦♦♦♦	♦	♦♦♦	♦♦♦	♦♦♦	♦	♦♦	♦	♦	♦♦♦	♦♦
Israel	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦
Italy	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Japan	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Libya	♦♦	♦	♦	♦	♦	♦	♦	♦	♦	♦♦	♦
North Korea	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦	♦♦♦	♦♦♦♦	♦♦♦
Pakistan	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦	♦	♦♦	♦	♦♦	♦♦	♦♦
Russia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
South Africa	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦
South Korea	♦♦	♦♦	♦♦♦	♦♦	♦♦	♦♦	♦♦	♦♦♦	♦♦	♦♦♦	♦♦♦
Sweden	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦♦♦♦	♦♦♦	♦♦♦♦
Syria	♦♦	♦♦	♦♦	♦♦	♦	♦	♦	♦	♦	♦♦♦	♦
Taiwan	♦♦♦	♦♦	♦♦♦	♦♦	♦♦	♦♦	♦♦	♦♦♦♦	♦♦	♦♦	♦♦♦♦
Ukraine	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United Kingdom	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United States	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦

Legend: Sufficient Technologies Capabilities: ♦♦♦♦ exceeds sufficient level ♦♦♦ sufficient level ♦♦ some ♦ limited

Because two or more countries have the same number of diamonds does not mean that their capabilities are the same. An absence of diamonds in countries of concern may indicate an absence of information, not of capability. The absence of a country from this list may indicate an absence of information, not capability.

Figure 1.1-1. Theater Ballistic Missiles Foreign Technology Assessment Summary

Table 1.1-1. Theater Ballistic Missiles Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
AIRFRAME					
Complete missile systems (Propellants having >86% total solids)	Capable of delivering >500 kg to >300 km	WA ML 4; MTCR 1; USML IV	None identified	None identified	Automatic-guidance/ target-loading software
NC turning machines or NC turning/milling machines	Rotary tables >1.0 m	WA Cat. 2B; CCL Cat. 2B; NDUL 1	None identified	Optical alignment and surface finish measuring equipment; roller and thrust bearings capable of maintaining tolerances to within 0.001 in.	Machine tool control software
Acid etch metal removal	Masking and etching facilities to remove <0.001 in. layers of metal from complex shapes	CCL EAR 99	None identified	Acid baths and handling equipment	None identified
Spin, flow, and shear forming machines	Capability to manufacture curvilinear or cylindrical cross-section parts of 0.1 in. thickness or less	WA Cat. 2B; CCL 2B MTCR 3; NDUL 1	None identified	Thermal and viscosity constant flow controls	None identified
Automated welding equipment	Capable of producing longitudinal welds up to 10 m and circumferential welds on 0.8-m diameter or larger cylinders	CCL EAR 99	None identified	Jigs and frames to maintain shapes and rotate large cylinders	None identified
Composite filament winding equipment	Two or more axis control of filament placement	WA Cat. 1B; MTCR 6; CCL 1B	Aramid fiber	None identified	Helical winding logic
Composite tape laying equipment	Two axis or more control of tape placement	WA Cat. 1B; MTCR 6; CCL 1B	None identified	None identified	Tape supply and tension numerical controls
Composite weaving or interlacing equipment	Two-dimensional or more automated broad goods production of carbon carbon and woven fabric	WA Cat. 1B; MTCR 6; CCL 1B	Aramid fiber	None identified	Numerical control of the weaving process

(cont'd)

Table 1.1-1. Theater Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Hot melt prepregs for composite materials	Filament tensile strength >100,000 psi. and a melting or sublimation point >1,649 °C	WA Cat. 1C; CCL Cat. 1C; MTCR 8	Prepreg material produced from phenolic or epoxy resins	Hot melt prepreg machine	None identified
Adaptive aerodynamic control surfaces and actuators	Capable of producing a vehicle pitch rate of 1 deg/sec and control response to <10 Hz perturbations	WA ML 4, 10; USML IV; MTCR 10	None identified	None identified	Digital transducer reduction and position measurement (unless analog controlled)
Mach 0.9 and greater wind tunnels	None identified	WA Cat. 9B; MTCR 15; CCL 9B	None identified	Schlieren photography or other flow field phenomena recording instruments	Automatic data reduction software that predicts aerodynamic coefficients from subscale model force and moment measurements
Blow-down tunnels	Blow-down piping and valves to create 1.6 million Re on models of <= 2 in. length	WA Cat. 9B; MTCR 15; CCL Cat. 9B	High-pressure storage vessels; blow-down piping	Short response time instrumentation	Software for sequencing of instructions
Digital control, closed-loop vibration test equipment	Vibration spectrum between 20 and 5,000 Hz at 10 g's rms	WA Cat. 9B; MTCR 15; CCL Cat. 9B	Low impedance feedback transducers and spectral calibration equipment	Calibration equipment	Data reduction software employing advanced signal processing techniques such as Fast Fourier transform and "chirp" calculations

(cont'd)

Table 1.1-1. Theater Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
PROPULSION					
Solid propellant motors	Total impulse of >1,000,000 lb f-sec	WA Cat. 9A; MTCR 2, 20; CCL Cat. 9A; USML IV	Liners, insulation, adhesives, and case materials to withstand high pressures (2,500 psi or greater) and temperatures (2,400 °F or greater)	High-energy x-ray machines; rocket test stands; CT machines	None identified
Liquid propellant engines	Total impulse of >1,000,000 lb f-sec	WA Cat 9A; MTCR 2, 20; CCL Cat. 9A; USML IV	Valves and piping with flow-control deviation no greater than 0.5% and duty cycle timing deviation <20 msec	Rocket test stands; valves and piping with flow control deviation no greater than 0.5% and duty cycle timing deviation <20 msec	None identified
Solid propellants	Solid composite propellant that produces a theoretical sea-level Isp of 255 sec	MTCR 4; CCL Cat. 1C; USML V	Appropriately sized, sufficiently pure and uncontaminated oxidizer, fuel, and additives	"T cell" propellant burners and equipment instrumented to detect flow oscillations in segmented solid rocket grains	Programs that calculate thrust time traces for given internal grain cutouts
Ultrafine ammonium perchlorate (UFAP) size filtration and size gauges	The principal energetic ingredient within a solid-propellant formulation providing oxygen or oxidizing species to react with fuel	WA ML 8; USML V; MTCR 4; CCL Cat. 1C	Uniformly fine (5–50 µm) ammonium perchlorate or energetic oxidizers such as RDX, ADN, CL-20, HNF, and HAN	Electrolytic cells, crystallizer and separator to produce uniform particles of pure AP. Other energetic oxidizers now being considered for ballistic missile application require unique production equipment not yet identified	None identified
Solid propellant additives	Additives used to modify propellant burning rate, viscosity, curing rate, bonding, moisture resistance, chemical deterioration, and aging	WA ML 8; USML V; MTCR 4; CCL Cat. 1C	MAPO, TEPAN, Catocene, Butacene	None identified	None identified
Turbopumps	Shaft speeds >8,000 RPM or discharge pressures >7,000 KPa	MTCR 3; USML IV	None identified	Large torsion shaft dynamometers	None identified

(cont'd)

Table 1.1-1. Theater Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Rocket motor/engine test stands	Test stands capable of withstanding a thrust of >20,000 lb.	MTCR 15; CCL Cat. 9B; USML IV	None identified	High frame rate cameras that are shock, vibration and thermal hardened; Thrust measurement hardware	None identified
Thrust vector control (for strap-on or multiple body missiles)	Steering guidance for multiple-body missiles that produces in excess of 1 deg/ sec pitch rate and control for <10 Hz oscillations	MTCR 2; USML IV	High atomic weight injection fluid for steering and pitch control; carbon carbon or other heat and flame tolerant material for jet vanes	Thrust stand with torsional force and moment measurement capability to determine pitch and roll forces and moments	Adaptive software to calculate theoretical positional change with measured position change in flight and compensate for the difference
Telemetry or encrypted telemetry data transmission hardware	Transmission rates of 20 kbit/s or analog equivalent and operation in a high vibration environment	CCL Cat.5A-P1; USML X; WA Cat. 5A-P1; WA ML 11; MTCR 12	None identified	Calibration equipment with 100 kbit/s sample and hold capability	Encryption algorithms of DES standard 40 bit and higher
Fluid energy mills for grinding and mixing highly energetic materials	Explosion-resistant equipment designed to handle energetic materials	WA ML 18; MTCR 5; USML XXI	None identified	None identified	None identified
GUIDANCE, CONTROL, AND NAVIGATION					
Inertial measurement units	Boost cut off command signals within 0.25 deg of programmed injection angle, 2% of burnout altitude, and 1% of burnout velocity	WA ML 11; MTCR 9; WA Cat. 7A; CCL Cat. 7A; USML XV	None identified	Vibration environmental test facilities sometimes combined with centrifuges	Efficient software algorithms that support major cycle time of <50 msec.
Radio command guidance	Boost cut off command signals within 0.25 deg of programmed injection angle, 2% of burnout altitude, and 1% of burnout velocity.	CCL Cat.5A-P1; USML XV	None identified	None identified	Efficient software algorithms that support major cycle time of 50 msec

(cont'd)

Table 1.1-1. Theater Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Ground-based "GPS" systems	Position accuracy of 1 m	CCL Cat. 7A; WA Cat. 7A; MTCR 11; USML XV	None identified	Calibration test articles that can be placed in and move through the measurement field; time clocks with signal accuracy <1 micro-second	Nonlinear multiple equation solving algorithms based on matrix mathematics and Doppler corrections
Propulsion/airframe/ flight control system integration	Provide optimum system performance within confines of airframe/propulsion system architecture to meet mission requirements	WA ML 11; MTCR 10; USML XV	None identified	Six degrees of freedom computer model	Source code for CAD/CAE
Thrust vector control technologies	Missile pitch rate of 2 deg/sec	MTCR 2; USML IV	None identified	None identified	Efficient software algorithms that support major cycle time of <50 msec
High-frequency piezoelectric instrumentation	Pressure gauges with 25 khz response and 0.1% linearity; Force transducers with <50 Hz response and 0.1% linearity	CCL EAR 99	None identified	Calibration equipment	None identified
Servo valves	Flow rates >24 liters per minute, at absolute pressures of >7,000 KPa (1,000 psi) and have actuator response time to support control of <50 msec.	MTCR 3; USML IV	None identified	Hysteresis loop measurement equipment	None identified
WEAPONS INTEGRATION					
Weapons Separation Technology	Warhead separation with no greater than 0.5 m/sec velocity change or 1 deg injection angle change	MTCR 3; USML XV	None identified	Separation firing circuits and exploding bridge wire charges with 20 msec. or less deviance	Timing circuit and sequencing logic
Ablative heat shields or whole RVs with ablative heat shields	Ablation rates of less than 3 mm/sec at 2 km/sec or greater reentry velocity	MTCR 2; USML IV	Carbon carbon or other materials with heat capacities >11 MJ/kg (5,000 BTU/lb)	Arcjets	None identified

(cont'd)

Table 1.1-1. Theater Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Heat sink or whole RVs with heat sink	Material capable of sustaining 1,000 BTU/lb.	MTCR 2; USML IV	None identified	Test ranges	None identified
Transporter/Erector Launchers (TELs) for surface to surface missile systems	Launchers capable of leveling to within 0.001 deg of Earth-centered ellipsoidal axis and with firing tables capable of 0.02-deg launch azimuth	WA ML 4; USML IV; MTCR 12	None identified	Theodolites automatic load levelers and high precision surveying equipment or GPS-based surveying equipment (or equivalent)	Automatic targeting software including geographic algorithms that calculate trajectory corrections for difference in launch and target point elevations
Safing, arming, and fuzing for chemical and biological weapons	Multi-step arming devices that arm and fuze based on telemetered radar signals, measurements of g's, barometric pressure, flight time, altitude, or other physical variable with <50 msec response time	WA ML 4; MTCR 2; USML IV	None identified	High energy density batteries and fast rise time firing circuits	None identified
Submunitions separation or dispensing mechanisms	Designed to meet individual system mission performance requirements under worldwide environmental conditions	WA ML 4; USML IV	None identified	Aerodynamic braking hardware, parachutes, split flap control hardware	None identified

Table 1.1-2. Theater Ballistic Missiles Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
AIRFRAME			
Complete missile systems (Propellants having >86% total solids)	Longer range missiles can be constructed from existing airframes by clustering engines, booster strap-ons, and stretched tanks	Ranges above 1,000 km allow proliferants to reach targets of United States interest	Cruise missiles, manned bombers and tactical aircraft
NC turning machines or NC turning/ milling machines	Bell-shaped missile nozzles are difficult to make without numerical control	All TBM systems	Non-NC turning/milling machines
Acid etch metal removal	Control and removal of material	Additional payload may replace removed structural and excess structural material mass	Machining of complex contours
Spin, flow, and shear forming machines	Designing and forming complex shapes that are required for aerodynamic or structural efficiency	Increases either range or payload capability	Sheet metal brakes and stamping equipment
Automated welding equipment	Air frames are structurally stronger and aerodynamically smoother with advanced welding techniques	Reduces unpredictable flight characteristics improves accuracy	Conventional welding
Composite filament-winding equipment	Higher strength-to-weight ratio materials allow use of high Isp solid propellants	High Isp solid-fueled rockets yield significant range increases and are easier to fire and maintain	Steel cases
Composite tape-laying equipment	Higher strength-to-weight ratio materials allow use of high Isp solid propellants	High Isp solid-fueled rockets yield significant range increases and are easier to fire and maintain	Steel cases
Composite weaving or interlacing equipment	Higher temperature performing materials	All TBM systems	Metal or ceramic nozzle throat sections and heat sink re-entry vehicle nose tips
Hot melt prepregs for composite materials	Reduces use of more costly and difficult methods to create uniform resin/filament composite	May be used to manufacture solid-propellant rocket cases for higher range and payload performance	None identified
Adaptive aerodynamic control surfaces and actuators	Solving the guidance equations in a closed loop(s) to create adaptive changes in near real time	More accurate boost-phase guidance produces lower CEPs	Open loop guidance with error corrections performed by a post-boost vehicle or Attitude Control Module (ACM)
Wind tunnels capable of Mach 0.9 or greater	Studies of high ballistic coefficient reentry vehicles requires speeds >Mach 0.9	More accurate reentry vehicles for better CEP and maintaining better control by retaining more of the reentry velocity	Flight testing

(cont'd)

Table 1.1-2. Theater Ballistic Missiles Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Blow down tunnels	Provision of pressurized gas supply and instrumentation capable of simulating flight conditions beyond those provided by continuous flow wind tunnels	Indigenous research in aerodynamic variables leading to better flight predictions and lower CEPs	Extrapolations from lower Reynolds number subscale models
Digital control, closed-loop vibration test equipment	Prediction of vibration modes	Structural efficiency increases range and/or payload capability	Analog computers or finite element codes without experimental validation
PROPULSION			
Solid propellant motors	Casting and curing either case-bonded or cartridge-loaded propellant without cracking or delaminations	Indigenous production of second stages for existing missiles allows a proliferant to extend range	Liquid propellant engines
Liquid propellant engines	Increasing the propellant flow rate and combustion chamber pressure/ temperature, by using such processes as regenerative cooling, without damaging the engine	Engines in existing missiles can be replaced with higher performance engines for extended range or payload	Solid propellant motors
Solid propellants	Increasing the Isp of the propellant	Solid propellant missiles are difficult to locate and target because of their simplicity, storability, and smaller support train	Liquid propellants
Solid propellant oxidizers	Increasing the oxidizer efficiency and supporting faster burn rates by the reduction in particle size	Better oxidizers provide a more efficient, longer range missile	None identified
Solid propellant additives	Achieving the desired propellant properties (e.g., burn rate, deflagration control, flow stability) with unconventional materials	Propellant signature modification disguises a launch for cueing satellites, which direct missile defense batteries	None identified
Turbopumps	Increasing propellant and oxidizer flow to the thrust chamber	Modern, higher performance turbopumps make liquid propellant missiles more reliable	Ullage tanks

(cont'd)

Table 1.1-2. Theater Ballistic Missiles Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Rocket motor/engine test stands	Accurately measuring the force and torsional response of the stand to generate an accurate thrust time profile	Thrust time profiles allow proliferants fly on unusual trajectories (e.g., depressed or lofted)	None identified
Thrust vector control (For strap-on or multiple body missiles)	Predicting the proper mixture ratios and flow rates under dynamic conditions to precisely control the flight	Compensate for misfired cluster engines and control the flight path of the missile	Aerodynamic surfaces
Telemetry or encrypted telemetry data transmission hardware	Real time encryption and transmission of data from a moving vehicle	Prevents observers from understand-ing the intention of the missile flight and static test programs	Open channel communication
Fluid energy mills for grinding and mixing highly energetic materials	Safety of personnel and facilities	Manufacture of high Isp propellants and oxidizers	Older, more dangerous facilities
GUIDANCE, CONTROL, AND NAVIGATION			
Inertial measurement units	Low drift rate and g insensitive response in accelerometers and gyros	Reduced CEP to support military targeting	Radio command guidance; Ground-based GPS
Radio command guidance	Line-of-sight command guidance	Highly accurate guidance for reduced CEP that does not require extensive improvement in gyros or accelerometers	Ground-based GPS; IMUs
Ground-based "GPS"systems	Signal timing and transmission	Jam-free, highly accurate, boost-phase guidance for reduced CEP	IMUs; Radio command guidance
Propulsion/airframe/flight control system integration	Aligning guidance and control system inertial space reference with geometric reference of airframe	Reduced CEP and higher azimuth accuracy	Post boost vehicles and ACMs which steer out boost inaccuracy
Thrust vector control technologies	Making adaptive corrections for a variety of flight profiles	Supports real time targeting by allowing variable flight profiles to be used as military situation changes	Aerodynamic control surfaces such as fins
High-frequency piezoelectric instrumentation	Reducing or transmitting data and evaluating the data from flight tests, static tests or actual launches	All military air vehicles	Low frequency analog transducers

(cont'd)

Table 1.1-2. Theater Ballistic Missiles Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Servo valves	Making control loop time constant consistent with flight requirements	Lower time constant servo valves increase the range of the missile by allowing the removal of fins or other aerodynamic controls surfaces or increase the accuracy on finned missiles	None identified
WEAPONS INTEGRATION			
Weapons Separation Technology	Incorporating separating warheads into the flight profile	Separating warheads reduce the CEP error contribution during the reentry phase of flight; complicates defense	Non-separation of warheads
Ablative heat shields or whole RVs with ablative heat shields	Reducing ablation rate of the nose tip	Ablative heat shields permit the design of high ballistic coefficient re-entry vehicles which have better penetration of missile defenses	Low-ballistic coefficient re-entry with blunt-nosed re-entry vehicles
Heat sink or whole RVs with heat sink	Building heat sinks into a warhead without decreasing the packing fraction to unacceptable levels for high ballistic coefficient vehicles	Heat sinks may be used with biological warheads when the packing fraction is not as important as lowering the exposure temperature of a live agent	Low-ballistic coefficients reentry with blunt-nosed re-entry vehicles
Transporter/Erector Launchers (TELs) for surface to surface missile systems	Reducing the setup and strike down time for launch operations and remote location azimuth of mobile launches	Reduced operation times lower the possibility of counter battery fire to destroy the TELs which are high-value components of a missile force	Fixed launch sites
Safing, arming, and fuzing for chemical and biological weapons	Reducing the compound probability of failures of multiple step arming, safing, fuzing, and firing operations	Allows for more accurate and effective delivery of chemical and biological warheads	Single-stage timing devices, g sensors or altimeters
Submunitions separation or dispensing mechanisms	Separating submunitions without inducing additional velocity or injection angle error and maintaining the viability of warhead	Allows for more accurate and effective delivery of chemical and biological warheads	Maneuvering re-entry vehicles

SECTION 1.2—INTERCONTINENTAL BALLISTIC MISSILES (ICBMs)

OVERVIEW

The Intercontinental Ballistic Missiles (ICBMs) subsection continues the description of missile technology that was begun in the TBM section and extends it to the additional technologies that a nation needs to increase the range of its missiles to intercontinental distances (>5,500 km). ICBMs are particularly troubling to the world community because they have few, if any, distinguishing characteristics from space launch vehicles. Many nations can build an ICBM capability while claiming to be building a space launch fleet. Few would question, for instance, India's assertion about the benefits of a communication satellite to link remote regions in its country or a meteorological satellite to predict the path of monsoons. If a country chooses to further assert that national sovereignty compels it to build its own launch vehicle, the world community has few legitimate reasons to argue.

In the last 20 years, several countries have built, or sought to build, missiles with an intercontinental reach, usually under the auspices of a space launch capability. France led the way with the introduction of the S-2 launch vehicle in the late 1960's. Derivatives and motor technology from their S-2 missile assisted France in developing its Ariane space launch vehicle, which competes directly with the American Delta class space vehicles. Israel demonstrated the technical capacity to put a satellite in orbit in 1991, indicating to the world that it could deliver WMD to any spot on the globe.

Space launch programs came out of South Africa and India in the late 1980's. The South Africans constructed an especially credible prototype for a three-stage launch vehicle that had immediate use as an ICBM. Finally, Iraq showed that a long-range missile did not necessarily have to be built from the ground up. With the help of foreign consultants, Iraq test fired the al Abid Space Launch Vehicle in December 1990. The al Abid consisted of five SCUD missiles strapped together to form a lower stage, which was designed to boost two upper stages, together with a payload, into orbit. The al Abid did not work as predicted, and, if it had, it would have put only a few kilograms of useful payload into orbit. As an ICBM, though, it established the possibility of building a long-range rocket from dated technology. The various technologies will be addressed as complete *systems* and as *subsystems.*

Highlights

- Strap-on boosters are an attractive method to develop ICBMs quickly.
- Serially staged missiles deliver the most payload per unit weight, but are more difficult to make.
- ICBMs cost a proliferant 20 to 60 times as much as a TBM for the same payload.
- Proliferants will need to manufacture Transporter-Erector Launchers (TELs) if they seek a mobile missile capability, or build hardened shelters if they wish to protect ICBM.
- Chemical and biological agents are difficult to dispense effectively from an ICBM.
- A proliferant may solve the ICBM re-entry heating problem by building a less accurate, low ballistic coefficient re-entry vehicle.
- A post-boost vehicle provides a means of delivering WMD accurately from an ICBM.

Systems

Iraq built its al Abid capability with the direct assistance of foreign scientists and engineers and by attempting to purchase technology, such as carbon-carbon materials, for rocket nozzle throats and nosetips directly from foreign companies. The multiple uses for aerospace materials and the development of aerospace consortiums have multiplied the number of sources of research talent and manufacturing industries that a potential proliferant nation can tap for assistance in building an ICBM.

These foreign outlets have also exposed the proliferant world to the high expense associated with building an ICBM. In the late 1980's, Iraq could afford to trade some of its oil wealth for the cost of buying the entire corporate talent of one research and development (R&D) firm. Most economies that can sustain such a high level of funding are either already building space launch vehicles (France and China), are in a multilateral arrangement to build one (Germany, Great Britain, Italy), or have recently abandoned building one because of market forces (South Africa).

ICBM attacks must also be effective because a launching nation will get few opportunities to continue the attack. The simple cost of an ICBM limits the total size of a missile inventory. This decreases the potential for sustained firing of ICBMs, a tactic used to disrupt a society by the threat of repeated chemical weapons attacks by long-range missiles.

If a country seeks to launch an ICBM, it must either launch the missile from a vulnerable fixed launch site, harden the launch site for better survivability against attack, or invest the additional expense in building a mobile transporter-erector launcher (TEL). Use of vulnerable, fixed launch site ICBMs provides opportunity for opposing forces to eliminate most of these sites quickly. Hardened launch sites are difficult to reload quickly and thus damper a sustained firing tactic. Without the use of fixed launch sites, a nation must rely on mobile launchers. Making enough mobile launchers to support a long missile campaign is an expensive endeavor. It also lessens the possibility of a sustained firing. A small ICBM that delivers 500 kg of payload to a distance of 9,000 km will weigh between 15,000 and 22,000 kg, depending on the efficiency of the design and the sophistication of the technology involved. The FSU and the United States have built TELs to handle missiles of this mass.

Chemical or biological agents are not spread efficiently by the flight path that an ICBM follows. The high velocity along the flight azimuth makes it almost impossible to distribute airborne agents in an even and effective cloud. Submunitions make the problem somewhat more tractable, but the submunitions still require a very capable propulsion system if they are to cancel the azimuthal velocity and impart a cross range velocity to circularize the distribution of an agent cloud. Other problems abound: U.S. experience with fuzes for ballistic missiles showed that much less than 10 percent of chemical and biological agents survived the launch and delivery sequence. Iraq used fuzing for its chemical warheads on its TBMs that would have allowed less than 1 percent of the agent to survive.

The most sensible warhead for an ICBM to carry is a nuclear weapon, and the weaponization section concerns itself primarily with the weaponization of ICBMs to carry nuclear warheads.

Subsystems

Some of the same technologies for extending a TBM's range provide extra capability to build an ICBM. An ICBM may include strap-ons, a clustered combination of single-stage missiles, "parallel" staging, and serial staging. Iraq increased the range of its missile fleet by reducing the weight of the warhead in one case (the al Hussein missile) and extending the propellant and oxidizer tanks and increasing the burn time in another (the "al Abbas" missile). The particular path that Iraq followed in making the "al Abbas" out of SCUD parts is not technically practical for building an ICBM. An *airframe* must have a thrust-to-weight ratio of greater than one to lift off, and a SCUD airframe cannot be extended sufficiently to reach intercontinental ranges and still lift off with the current turbopump, given its low stage fraction (the ratio of burn-out weight to takeoff weight—a strong measure of missile performance). Building a new turbopump that provides the needed take-off thrust and also fits within the airframe is a more difficult task than simply building a new and much more capable missile from scratch.

Both strap-ons and parallel staging provide ways for a proliferant to reach an ICBM capability. Many countries have built small, solid rocket motors that can be tailored to fit within the MTCR guidelines. A number of these motors strapped on to a reasonably capable main stage, such as the S-2, would resemble the Ariane launch vehicle. The country that pursues this path requires a firing sequencer that can ignite all the motors simultaneously. Strap-ons generally operate for a short fraction (roughly one-third) of the total missile burn time of an ICBM. If they are dropped off, the guidance and control requirement can be met by using the main engine thrust vector control to steer the whole assemblage. Aerodynamically, the strap-ons behave much as fins in the lower atmosphere, increasing the amount of total cycle time available for the guidance computer to operate.

Parallel staging offers many of the same advantages for liquid rockets that strap-ons do for solid rockets. The United States built the Atlas missile as a parallel staged rocket because, in the 1950's, it was the quickest path to developing an ICBM to meet the Soviet challenge. A liquid-fueled, parallel-staged rocket draws propellant and oxidizer from existing tanks but feeds it to several engines at once to sustain the proper thrust level. When these engines are no longer needed, they are dropped. The tanks, however, remain with the missile so a parallel-staged missile is not as efficient as a serially staged missile.

As many designers already know, and most textbooks prove mathematically, a serially staged missile is the best design to deliver a payload to long distances. Examples of an optimal, serially staged ICBM include the U.S. Peacekeeper missile and the Soviet Union's SS-24. Each of these missiles can reach 11,000-km range and carry up to 10 nuclear warheads. In an optimum serially staged configuration, each stage contributes about twice as much velocity as the stage that preceded it, though many effective ICBMs can be built without following any particular design guideline.

To be capable of an 11,000-km range, the ideal ICBM would be composed of four stages. The United States and the Soviet Union both ignored this consideration, though, because of concerns about the overall reliability of the missile. The ignition of each stage in sequence at the staging interval is difficult to time properly, and, inevitably, some period occurs during this staging event when the control authority over the missile is at its worst. To reduce these events and improve the overall reliably of the missiles, the superpowers chose to trade performance for fewer stages.

A proliferant that does not buy a fully equipped ICBM must solve this same staging sequence problem. The technologies to build event sequencers and the short duration, reproducibly timed squibs, exploding bridge-wires, or other stage separation shaped charges to support these sequencers are among the most sensitive material to be controlled in trying to prevent the proliferation of ICBMs.

If a proliferant clusters existing single-stage missiles together, it must consider the *guidance and control* implications of the design. Several ordinary single-stage missiles grouped together make a very stout planform with a high lateral moment of inertia. To *control* this missile, the thrust vector control system has to produce much greater torque on the airframe than it would for an equivalent mass that is long and thin, as are most missiles. The high moment of inertia, in turn, requires either higher actuation strokes in a thrust vector control system, which reduces the thrust available for range, or a much larger liquid injection system, which reduces the weight available for propellant and again reduces the range. On the other hand, simple thrust vector control strategies, such as vernier nozzles and fluid injection, can satisfactorily control the missile. A proliferant only needs to build the fluidics to support these schemes: fast acting valves and the actuators to control these valves. The same types of valve and piping concerns that are covered in the tables for TBMs apply to the fluid system of an ICBM.

A serially staged missile forces a designer to carefully consider the control of a more dynamically complex vehicle. The stages and interstage breaks make the structure of a serially staged missile behave under some loading conditions as a series of smaller integral segments attached at points with flexible joints. This construction has natural frequencies that are different than a single, integral body, such as a one-stage missile. If flight conditions excite any of these many and complex resonant modes in the missile stack, the guidance and control system must supply the correct damping motion, in frequency or duration, to prevent the missile from losing control. Some of the corrections affect the guidance of the missile, and the flight computer must determine the proper steering to return the missile to its predicted trajectory. A proliferator may use many existing finite element routines and modal analysis hardware to find or predict these frequencies.

In addition to the hardware, a requirement exists to test and validate the computer routines in wind tunnels and structural laboratories. Since these computer routines reduce the number of engineers needed to modify missiles, they are particularly key to reducing the cost of individual missiles. For this reason, automated engineering computer routines are ranked at the same level of threat in the technology tables as hardware items.

The guidance and navigation systems of an ICBM closely mirror those that are used in a TBM, and anyone who has passed through the phase of building a TBM can possibly scale up a version of the guidance system suitable from the earlier missiles. The mathematical logic for determining range is different for ICBMs than for TBMs if a digital guidance computer is used rather than a pendulous integrating gyro accelerometer, which is the standard for most TBMs. However, many text books derive the equations of motion for digital guidance computers. Errors created by the guidance system feedback instrumentation during the boost-phase can be corrected later in the flight with post-boost vehicles (to be discussed in the weaponization section). *Navigation* technologies, beyond the issues already discussed for TBMs, can be applied in this same post-boost vehicle.

The *propulsion* system of ICBMs can be either liquid or solid fueled (or in some cases a hybrid of the two). A proliferator that understands the principles of solid fuel burning and how to shape the configuration of the internal grain to achieve the desired thrust/time trace can build any of its stages for an ICBM indigenously. Larger motors, of course, are more difficult to manufacture. The outer case of a solid missile can be made from any conventional material, such as steel, but better propellants with higher burning temperatures often require the substitution of materials with higher strength-to-weight ratios, such as Kevlar and carbon or glass epoxy. Steel cases can be used with cross-linked, double-based solid fuels, but the need for additional liners and insulation to protect the case against the higher burning temperatures of these newer propellants compromises some of the range that can be achieved by using the better propellant in the first place. Most steel cases must be produced from a material having a thickness that closely or exactly matches the final thickness of the motor case to prevent excessive milling of the material.

Filament winding technology may lay the filaments in solid motor cases in longitudinal and circumferential plies, in bias plies, and in the most structurally efficient way of all—in helically wound orientations. Any European, former Soviet, or U.S. multi-axis filament-winding machine of sufficient size can be used to wind a solid rocket motor case. The ply's winding orientation determines the structural, or stage, efficiency of the solid rocket motor.

In a liquid-fueled missile, the supply pressure to feed fuel and oxidizer to the thrust chamber may come either from creating an ullage pressure or pumping the liquids to the thrust chamber with turbopumps. Large volume flow rate pumps, particularly those designed for caustic fuels, have unique applications to ICBM construction. A proliferant may avoid the need for pumps by building tanks within the ICBM to contain an ullage pressure, which forces the liquids into the thrust chambers when the tanks are exposed to this high pressure. In most cases, ullage pressure is structurally less efficient than modern turbopumps because the missile frame must cover the ullage tanks, which are maintained at very high pressure and thus are quite heavy. However, this decrement in range performance is small. Since the technology is simpler to obtain, it may serve the needs of a proliferant. In either case, a liquid missile generally requires valves and gauges that are lightweight, operate with sub-millisecond time cycles, and have a reliable and reproducible operation time. These valves must also accept electrical signals from standard computer interfaces and require little, if any, ancillary electrical equipment.

The choice of liquid propellant may also influence other technology choices. Some liquid propellants are storable, and others must be cryogenically cooled to temperatures approaching absolute zero. The cryogenic coolers make the missile less mobile and more difficult to prepare to fire. The superpowers long ago abandoned nonstorable liquid-propellant missiles for these reasons, but a country that can support the technology to manufacture and store liquid oxygen and hydrogen may find this to be one possible path to making an ICBM.

The ICBM trajectory creates the most stressing problem for *weapons integration,* mainly because of the enormous heat load that velocity imparts to the reentry vehicle (RV). A TBM reenters the atmosphere at about 2 km/sec, and an ICBM reenters at about 6 km/sec. This increase in velocity creates more than an order of magnitude increase in associated heating.

Traditionally, ICBMs have overcome the heat load with two reentry strategies: one using a very high ballistic coefficient and one using a very low ballistic coefficient. The choice has important and mutually exclusive implications for other aspects of the design. If a low ballistic coefficient is selected for RVs, it may only require that the heat shield be built from very simple and easy to obtain material, such as cork and phenolic. These materials provide sufficient thermal protection because the velocity of the RV is dissipated high in the atmosphere and the surplus thermal energy is transferred to the shock wave that the RV creates and the turbulence of the flow in its wake. Since the RV has slowed almost to terminal velocity, the unpredictable conditions of the winds aloft reduce accuracy. A low ballistic coefficient RV may have a circular error probability (CEP) as great as 20 km from the reentry phase of its flight alone. It has, however, slowed to the point where the dissemination of chemical and biological agents is more feasible.

On the other hand, if a high ballistic coefficient is selected, the nosetip of the RV must endure temperatures in excess of 2,000 °C. Temperatures in this range call for the best thermal insulating materials possible, such as 3-d or 4-d carbon/carbon. In addition to protecting the RV from extreme heating, the nosetip must also experience very little erosion of its contour as it travels through the atmosphere. Materials that provide both of these properties are rare and generally limited to manufacture in technologically advanced countries.

Either of these reentry strategies benefits from the aid of a post-boost vehicle (PBV). The use of a PBV makes a high ballistic coefficient RV especially accurate. The PBV operates in space after the missile has burned completely. It steers out the guidance errors that have accumulated during the boost phase of the firing and puts the RV on a more accurate ballistic path. It can also be used just before the RV reenters the atmosphere to correct any errors in the flight path that have occurred because of assumptions about the Earth's gravitational field between the launch point and the target. In a sophisticated PBV, the vehicle may realign the RV so it reenters the atmosphere with little aerodynamic oscillation. It may also spin the RV to even out contour changes in the nosetip and, thereby, reduce unpredictable flow fields around the body. The spinning gives the RV a gyroscopic inertia that damps out small perturbations in the attitude of the RV.

With a PBV, a proliferator can achieve a targeting accuracy of 500 m over an intercontinental range. In general, the PBV costs about half of the total throw weight of a missile. For these reasons, its use is traded off with chemical and biological agents payload.

The tables include technologies for extending range by simple modifications to boosters, separating a warhead so it can re-enter, making a thrust vector control system that is consistent with the higher aerodynamic and thrust loads on an ICBM, and increasing the responsiveness of thrust vector control. The tables list first the most useful technologies for range extension and for building complete motors for an ICBM. Then, they list in descending order those technologies that advance capability to (1) build a large arsenal very quickly; (2) allow a warhead to reenter the atmosphere without burning up; (3) develop more accurate warheads from the post-boost phase through the reentry phase; and (4) support an ICBM arsenal with other military equipment, such as silos or other protected launch sites. As in other subsections, each of the tabulated technologies, or adaptations of technologies, applies to a specific subsystem of the missile: *airframe, propulsion, guidance control and navigation*, and *weapons integration*. The "Foreign Technology Assessment" paragraphs explore these programs in greater depth and evaluate the technical depth of various nations that are trying to build space launch vehicles and ICBMs.

RATIONALE

ICBMs create a true proliferation problem because they enable the proliferator to break out of a regional context and move toward potential global impact. Regardless of the origin of a conflict, a proliferator may involve the entire world simply by threatening to spread the war with an ICBM. In 1991, Iraq demonstrated this principle even with the limited-range "al Abbas" missile.

Whatever unspoken protocols existed during the Cold War, they will almost certainly cease to exist when an ICBM-armed proliferator makes threats against a target. Therefore, the ICBM subsection emphasizes technologies that pose the most immediate threat against the United States and its allies, assuming that no ballistic missile defenses are readily available.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 1.2-1)

Systems

Seven nations—the United States, Russia, China, France, Japan, India, and Israel—have launched space vehicles, demonstrating generalized capability to build an ICBM. Israel has demonstrated the clearest link between a space launch program and a missile delivery system with the Shavit, the first Israeli satellite, and a substantial copy and scaled-up version of the Jericho II missile. Although Ukraine has not "launched" any space vehicles, it has produced large space launch systems as well as the world's only heavy ICBM, the SS-18. Brazil is developing a sounding rocket that has applications to an ICBM program, and Pakistan has made first-generation rockets that indicate an underlying objective of developing an ICBM. No country has yet sold ICBMs abroad.

Under United States pressure, Taiwan all but abandoned its space launch program in 1993. However, a residual infrastructure of knowledge and manufacturing capability remains in Taiwan. South Korea and Indonesia, once ICBM aspirants, have also dropped their development programs in recent years because of U.S. pressure and economic forces.

No one purchaser names a possible price for the purchase of an ICBM, since none have been sold as unregulated commodities in the way that SCUDs have. However, other sales provide some indication of the rough costs. The Brazilians reportedly expected to receive in excess of $10 million each for their Condor II, whose range of 1,000 km is much less than intercontinental, and the Chinese apparently received about $20 million for each of the 2,500-km range CSS-2s they sold to Saudi Arabia. Many studies within the United States indicate that the Peacekeeper, a highly capable and advanced missile, costs the military about $65 million per copy.

At $50 million per missile, a country would need to invest about $2 billion to purchase or build 40 missiles. When this is compared to the roughly $200 million the Iraqis paid to build their Saad 16 missile manufacturing facility, it becomes clear that the economies of many countries cannot support a nuclear weapons production capability and an ICBM launch capability.

Existing ICBMs and their countries of origin include: China, the CSS-4; France, the M5 and M4; the FSU, the SS-11, -13, -17, -18, -19, -24, -25, and the SSN-20 and -23; and the United States, the MM III, Peacekeeper, and Trident.

Subsystems

A determined proliferant can make an ICBM by substituting many technologies for the ones that have been listed so far as being militarily sufficient. The proliferants that have not been named as already capable of building an ICBM—Iran, Iraq, Syria, and Libya—need to seek out certain technologies on overseas markets. The nature of an acquisition program need not reveal its intention, if substitutions for certain materials are done properly.

Hardware

Iran, Iraq, Syria, and Libya can manufacture or import steel of an equivalent grade to the material found in the early Minuteman II ICBM. If these countries seek to build a composite motor case instead, they must purchase the filament-winding machine from the United States, the FSU, France, Germany, the UK, or South Africa. The Chinese may be able to supply a reverse engineered filament winding machine based on Soviet technology.

Other than the traditional solid-propellant manufacturing centers in France, Sweden, Norway, Germany, and the United States, many other European countries with arms manufacturing centers, such as the Czech Republic, have some solid-propellant capability. In addition, Pakistan can manufacture small, solid-propellant motors that can be used as strap-on boosters. South Africa also has an indigenous solid-propellant production capability, which, if it so desired, can export small solid-propellant motors.

Proliferators that may wish to follow the liquid-fueled path to ICBMs without using strap-ons are likely to purchase turbopumps primarily from Germany, Sweden, the United States, France, or Russia.

The guidance and control package that a country needs to support an ICBM depends upon the desired accuracy it expects to achieve with its missile. Without a PBV, this accuracy is going to be poor, and more rudimentary technology can be used. Any industrial/advanced nation manufactures equipment and parts that, when properly constructed, can be used to build an inertial measuring unit. In addition to the United States, a proliferant can turn to Belgium, Germany, France, Holland, Sweden, Norway, Finland, Austria, the Czech Republic, Hungary, Russia, Italy, China, North Korea, South Korea, Taiwan, Australia, New Zealand, Egypt, or India. In general, though, a guidance and control unit, using a digital guidance computer and consistent with a staged missile, cannot be built from cannibalized parts of older, analog guidance systems.

A PBV requires a small liquid rocket motor, cold gas thrusters, or many small total impulse solid rocket motors. These motors must be supported by a small guidance, control, and navigation unit that flies with the RVs until they are dropped. GPS units have wide application for this particular phase of the ICBM trajectory. Because of existing export controls, a proliferant would have to modify an over-the-counter GPS receiver to operate at high altitude and at ICBM velocities. The knowledge of how to build a GPS receiver is now widespread, however, and many individual hobbyists have built receivers that evade these restrictions. A modified GPS receiver or a GLONASS receiver is completely consistent with the needs of a PBV.

Technical Assistance

Besides supplying whole systems, many corporations and nations have offered technical assistance in the last 10 years to some emerging missile powers. German firms reportedly assisted the missile programs of Argentina, Brazil, Egypt, India, Iraq, and Libya. The Italians have offered assistance to Argentina, Egypt, and India. The French have participated in missile programs in Iraq and Pakistan. Israel has been accused by international arms regulators of participating in technology programs that lend a country the capability to build or modify a ballistic missile. The South Africans reportedly have received significant aid from the Israelis.

Most European countries can lend technical assistance to emerging missiles powers. The French have a long history of developing missiles, not only to support the Ariane space launch capability but to launch the *force de frappe* nuclear arsenal. The Italians have participated in the European Union space program that helped design the *Hermes* missile. While the British relied on American missile programs in the 1960’s to supply their TBM needs, a technical exchange program between Britain and the United States trained and educated a sizable pool of missile talent from the British Isles.

Country	Airframe			Propulsion			Guidance and Control			Weapons Integration		
	Serial Staging	Parallel Staging	Strap-on Boosters	High-Energy Solid Propel-lants	Large-Scale Cast Solid Grains	Large Turbo-pumps for Liquid Fuels	GPS for Post-Boost Vehicles (PBV)	Small Guidance Com-puters to fit on PBV	Terminally Guided Reentry Vehicles	Reentry Thermal Protection Materials	Post-Boost Vehicles	Bomblets
Argentina	♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦	♦♦	♦♦	♦	♦♦♦	♦♦	♦♦
Brazil	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦	♦♦♦	♦♦	♦♦
Canada	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦
Chile	♦	♦	♦♦	♦♦	♦	♦	♦	♦	♦	♦	♦	♦
China	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Egypt	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦	♦♦	♦	♦♦♦	♦♦	♦♦
France	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Germany	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
India	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦	♦♦	♦♦	♦	♦♦♦	♦♦	♦♦
Iran	♦	♦♦	♦♦	♦♦	♦	♦	♦	♦	♦	♦♦	♦	♦
Iraq	♦♦	♦♦	♦♦♦	♦♦♦	♦	♦	♦	♦	♦	♦♦	♦	♦
Israel	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Italy	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦
Japan	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Libya	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
North Korea	♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦♦	♦♦	♦♦	♦	♦♦	♦♦	♦♦
Pakistan	♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦	♦♦	♦	♦	♦♦	♦	♦♦
Russia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
South Africa	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦	♦♦♦	♦♦♦	♦♦♦
South Korea	♦♦	♦♦	♦♦	♦♦♦	♦♦	♦♦	♦	♦♦	♦	♦♦	♦♦	♦♦
Sweden	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦♦	♦♦♦	♦♦♦♦
Syria	♦	♦	♦	♦♦	♦	♦	♦	♦	♦	♦	♦	♦
Taiwan	♦♦	♦♦	♦♦	♦♦♦	♦♦	♦♦	♦♦	♦♦	♦	♦♦	♦♦	♦♦
Ukraine	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United Kingdom	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United States	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦

Legend: Sufficient Technologies Capabilities: ♦♦♦♦ exceeds sufficient level ♦♦♦ sufficient level ♦♦ some ♦ limited

Because two or more countries have the same number of diamonds does not mean that their capabilities are the same. An absence of diamonds in countries of concern may indicate an absence of information, not of capability. The absence of a country from this list may indicate an absence of information, not capability.

Figure 1.2-1. Intercontinental Ballistic Missiles Foreign Technology Assessment Summary

Table 1.2-1. Intercontinental Ballistic Missiles Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
AIRFRAME					
Small solid strap-on boosters (Solid boosters with propellants having >86% solids)	Capable of producing a total system thrust of 10,000 lb (vacuum)	MTCR 2; USML IV; WA Cat. 9A; CCL Cat. 9A	None identified	Rocket test stands; Shaker facilities for environmental testing	Internal grain burn profile calculation software
Serial staging hardware	First stage thrust level of 100,000 lb (vacuum)	MTCR 3; USML IV	None identified	Rocket test stands; Shaker facilities for environmental testing	None identified
Parallel staging hardware	Capable of producing a total system thrust of 100,000 lb (vacuum)	MTCR 3; USML IV	None identified	Rocket test stands; Shaker facilities for environmental testing	None identified
PROPULSION					
Thrust vector control systems	Equivalent to trapped ball joint demonstrated at vector angles of ~5 deg consistent with solid rocket operations	MTCR 2; USML IV	None identified	Environmental test and evaluation	None identified
Extendible nozzle exit cones	Extendible cones that can increase the upper atmosphere expansion ratio to 30:1	MTCR 2; USML IV	None identified	Cold gas generators or dynamic test facilities to reproduce flight conditions and exit pressures	None identified
Solid-propellant motors	Total impulse of >50,000 lb-sec	MTCR 2; USML IV; WA Cat. 9A; CCL Cat. 9A	Liners, insulation, adhesives, and case materials to withstand temperatures of 1000 °C or higher	High-energy x-ray machines; rocket test stands; CT machines	None identified
Liquid-propellant engines	Total impulse of >50,000 lb-sec	MTCR 2; USML IV; WA Cat. 9A; CCL Cat. 9A	None identified	Rocket test stands; valves and piping with flow control deviation no greater than 0.5% and duty cycle timing deviation <20 msec	None identified
Solid propellants	Propellants, dopants and additives that produce Isp = 275 sec or greater in finished missile	MTCR 4; CCL Cat. 1C; USML V	Geometrically homogenous aluminum powder and metal hydrides	"T cell" propellant burners and equipment instrumented to detect flow oscillations in segmented solid rocket grains	Programs that calculate thrust time traces for given internal grain cutouts

(cont'd)

Table 1.2-1. Intercontinental Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Solid propellant oxidizers	Specialty oxidizers that increase burn rate or burn stability	WA ML 8; USML V; MTCR 4; CCL Cat. 1C	Geometrically homogenous ultra-fine (dia. <0.002 in.) ammonium perchlorate or equivalent	UFAP size filtration and size gauges	None identified
Solid propellant additives	Additives that modify missile emission spectra, aid in reducing flow instability, contribute to thrust vector control or increase burn rate	WA ML 8; MTCR 4; USML V; CCL Cat. 1C	MAPO, TEPAN, Catocene, Butacene	None identified	None identified
Turbopumps	Shaft speeds >8,000 RPM or discharge pressures >7,000 KPa	MTCR 3; USML IV	None identified	Large torsion shaft dynamometers	None identified
Rocket motor/engine test stands	Test stands capable of withstanding a thrust of >20,000 lb	MTCR 15; CCL Cat. 9B; USML IV	None identified	High frame rate cameras that are shock, vibration and thermal hardened; Thrust measurement hardware	None identified
Thrust vector control	Steering guidance for multiple- body missiles that produces in excess of 1 deg/sec pitch rate and control for <10 Hz oscillations	MTCR 2; USML IV, XV	High atomic weight injection fluid for steering and pitch control	Thrust stand with torsional force and moment measurement capability to determine pitch and roll forces and moments	Adaptive software to calculate theoretical positional change with measured position change in flight and compensate for the difference
Telemetry or encrypted telemetry data transmission hardware	Transmission rates of 20 kbyte/sec or analog equivalent and operation in a high vibration environment	MTCR 12; CCL Cat. 5A-P1; CCL Cat. 5A-P2 USML XV; WA Cat. 5A-P1; WA Cat. 5A-P2; WA ML 11	None identified	Calibration equipment with 100 kbyte/sec sample and hold capability	Encryption algorithms of DES standard 40 bit and higher
Fluid energy mills for grinding and mixing highly energetic materials	Explosion-resistant equipment designed to handle energetic materials	WA ML 18; MTCR 5; USML XXI	None identified	Frictionless closure valves and valves without pinch closure	None identified

(cont'd)

Table 1.2-1. Intercontinental Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Propellants	Utilization of hydrazine and nitrogen-tetraoxide families	WA ML 8; MTCR 4; USML V	None identified	Propellant scrubbing equipment and vapor control technology; production equipment for hydrazine and nitrogen tetraoxide	None identified
GUIDANCE, CONTROL, AND NAVIGATION					
Vernier motor controls	Boost cut off command signals within 0.25 deg of programmed injection angle, 2% of burnout altitude and 1% of burnout velocity	USML XXI	None identified	Valves and valve control solenoids	Efficient software algorithms that support major cycle time of 50 msec
Small, lightweight, IMUs consistent with post-boost vehicles	IMUs capable of solving the Lambert guidance equations and updating PBV positions in a 50 ms major cycle time	EAR; MTCR 9; USML XV; CCL Cat. 7A	None identified	Flight test vehicles that allow subscale velocity and vibration calibrations; Small computers	Digital implementation of common guidance laws such as the Lambert guidance laws. Calculations of positions in space such as the range insensitive axis or the time insensitive axis
Stage timing sequencers for hot fly out staging	Operation times of staging events including squib firing in less than 250 ms with a repeatability of error of less than 25 ms	USML XXI; MTCR 3	None identified	None identified	Nonlinear multiple equation solving algorithms based on matrix mathematics and Doppler corrections
Propulsion/airframe/ flight control system integration	Provide optimum system performance within confines of airframe/propulsion system architecture to meet mission requirements	MTCR 9; WA ML 11; USML IV	None identified	None identified	None identified
WEAPONS INTEGRATION					
Nose tip material	Nose tip heat protection for RVs with ballistic coefficient in excess of 1,500 psf with 3 mm/sec or less of ablation at 2,000 °F	MTCR 8; USML IV	Carbon Carbon material or 3d carbon carbon material that can be exposed to temperatures in excess of 3,500 °F	Autoclave and furnaces capable of carbonizing and graphitizing materials	None identified

(cont'd)

Table 1.2-1. Intercontinental Ballistic Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Radar altimeter fusing	Fusing and firing accuracy of less than 1,000 ft regardless of trajectory or elevation of target	MTCR 2; WA ML 4; USML IV	None identified	Flight test vehicles that allow subscale velocity and vibration calibrations; radar antennas capable of operation in highly ionized environments	None identified
Submunitions separation or dispensing mechanisms	Circular pattern dispersal of chemical or biological submunitions of greater than 0.5-km radius at mean target elevation	WA ML 4; USML IV	None identified	Aerodynamic braking hardware, parachutes, split flap control hardware	None identified

Table 1.2-2. Intercontinental Ballistic Missiles Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
AIRFRAME			
Small solid strap-on boosters (Solid boosters with propellants having >86% solids)	Integration of booster strap-ons	Ranges above 1,000 km allow proliferants to reach targets of United States interest	Parallel staging; Serial staging
Serial staging hardware	Proper sequencing of staging	Maximum range for given missile weight, lower launch accelerations	Strap-on boosters; Parallel staging
Parallel staging hardware	Staging coordination	Reduces overall burn time of ICBM and therefore complicates tracking	Serial staging; strap-on boosters
PROPULSION			
Thrust vector control systems	Controlling and directing the high thrust of an ICBM first stage	Highly capable thrust vector control systems support a variety of targeting strategies	Less capable TVC systems adapted from theater missiles with very constrained trajectories
Extendible nozzle exit cones	Making a lightweight nozzle design that is rigid enough to accommodate moving parts	Increases range without motor modifications on solid rocket motors	Larger exit cones and related longer stage lengths
Solid-propellant motors	Casting and curing either case bonded or cartridge loaded propellant without cracking or delaminations	Indigenous production of second stages for existing missiles allows a proliferant to extend range	Liquid propellant engines
Liquid-propellant engines	Increasing the propellant flow rate and combustion chamber pressure/ temperature, by using such processes as regenerative cooling, without damaging the engine	Engines in existing missiles can be replaced with higher performance engines for extended range or payload	Solid propellant motors
Solid propellants	Increasing the Isp of the propellant	Solid propellant missiles are difficult to locate and target because of their simplicity, storability and smaller support train	Liquid propellants
Solid-propellant oxidizers	Increasing the oxidizer efficiency and supporting faster burn rates by the reduction in particle size	Better oxidizers provide a more efficient, longer range missile	None identified
Solid-propellant additives	Achieving the desired propellant properties (e.g., burn rate, deflagration control, flow stability) with unconventional materials	Propellant signature modification disguises a launch for cueing satellites, which direct missile defense batteries	None identified
Turbopumps	Increasing propellant and oxidizer flow to the thrust chamber	Modern, higher performance turbopumps make liquid propellant engines more reliable	Ullage tanks

(cont'd)

Table 1.2-2. Intercontinental Ballistic Missiles Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Rocket motor/engine test stands	Accurately measuring the force and torsional response of the stand to generate an accurate thrust time profile; flame containment and explosion isolation	Thrust time profiles allow proliferants to fly on unusual trajectories (e.g. depressed or lofted)	None identified
Thrust vector control	Predicting the proper mixture ratios and flow rates under dynamic conditions to precisely control the flight	Control the flight path of the missile	Aerodynamic surfaces
Telemetry or encrypted telemetry data transmission hardware	Real time encryption and transmission of data from a moving vehicle	Prevents observers from understanding the intention of missile flight and static test programs	Open channel communication
Fluid energy mills for grinding and mixing highly energetic materials	Modern solid propellants detonate in shock and spark environments and destroy facilities	Manufacture of high Isp propellants and oxidizers	Older, more dangerous facilities
Propellants	Adequate production and storage facilities	Increased range and payload	Other propellants
GUIDANCE, CONTROL, AND NAVIGATION			
Vernier motor controls	Flow control of steering motors or engines	Rocket-powered missiles	None identified
Small, lightweight, IMUs consistent with post-boost vehicles	Placing a capable IMU on a small final stage with limited thrust	Highly accurate guidance for reduced CEP	None identified
Stage timing sequencers for hot fly out staging	Signal timing and transmission	Increase reliability of ICBMs	None identified
Propulsion/airframe/flight control system integration	Aligning guidance and control system inertial space reference with geometric reference of vehicle	Reduced CEP and higher azimuth accuracy	Post-boost vehicles and ACMs which steer out boost inaccuracy

(cont'd)

Table 1.2-2. Intercontinental Ballistic Missiles Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
WEAPONS INTEGRATION			
Nose tip material	Dealing with severe aerothermal environment associated with high ballistic coefficients	All reentry vehicles	Low ballistic coefficient reentry vehicles with less advanced materials
Radar altimeter fusing	Transmitting and recovering signals through a highly ionized environment and through a radar window in the RV	Weapons requiring detonation at specific above ground altitude	Multiple step firing and fuzing circuits including G sensitive circuits that detect the point where aerodynamic and gravitational forces balance and then time a command signal
Submunitions separation or dispensing mechanisms	Releasing the submunitions at a velocity to disperse agent without destroying it	Increase dissemination efficiency when used in conjunction with low ballistic coefficient reentry vehicles	Low ballistic coefficients reentry with spherical reentry vehicles that reduce the reentry velocity high in the atmosphere. The acceptance of a large loss in accuracy is implied

SECTION 1.3—CRUISE MISSILES

OVERVIEW

The Cruise Missiles subsection reviews the many ways a proliferant can construct a cruise missile to deliver a WMD. The term cruise missile covers several vehicles and their capabilities, from the Chinese Silkworm (HY-2), which has a range of less than 105 km, to the U.S. Advanced Cruise Missile (ACM), which can fly to ranges of up to 3,000 km. These vehicles vary greatly in their speed and ability to penetrate defenses. All, however, meet the definition of a cruise missile: "an unmanned self-propelled guided vehicle that sustains flight through aerodynamic lift for most of its flight path and whose primary mission is to place an ordnance or special payload on a target." Proliferants can achieve a cruise missile capability by simply buying existing cruise missiles from supplier states and modifying them to meet a particular need, or they can make a complete system from readily available parts.

European aerospace firms, the FSU, and the Chinese have all sold many cruise missiles of one description or another to customers in proliferant and industrialized countries. In most cases, the performance of missiles is range limited and, in some cases, even payload limited, and their use as a carrier of WMD is probably confined to tactical applications. With the introduction of new guidance technologies, particularly the GPS, future cruise missiles will be more accurate and attractive to proliferants.

The United States introduced cruise missiles into its inventory when a combination of technologies reached a critical point in their development. Taken together, these same technologies can easily form the underpinnings for a capable unmanned aerial system. Except for Terrain Contour Matching (TERCOM), the 1990's have seen these technologies, or the knowledge of how to reproduce them, become widespread among industrialized and newly industrializing nations. The introduction of GPS and GLONASS eliminates the need for a country to rely on TERCOM navigation. A proliferator is not forced to seek out any other technologies to build a cruise missile, though many, such as rocket-assisted take-off units, may give a combatant more flexibility in using a cruise missile for a variety of combat operations.

Many proliferants have the scientific and research base to design airframes and build them to meet the needs of a cruise missile program. Arms control officials in the U.S. State Department and many of its overseas counterparts are attempting to reduce high volume serial production of cruise missiles, particularly ones that support a chemical or biological weapons infrastructure. Consequently, the tables identify technologies that assist the mass production of cruise missiles. Once a country has an assured supply of engines and guidance components, the path to a capable cruise missile fleet becomes easier.

Highlights

- Existing over-the-counter technology allows a proliferant to assemble a threatening cruise missile.
- Cruise missiles are ideally suited for the delivery of biological agents.
- Subsonic cruise missiles can survey a target for meteorological conditions before spreading agent.
- Supersonic cruise missiles may increase the probability of penetrating defenses.
- A supersonic/subsonic hybrid cruise missile is difficult for a proliferant to build.
- Wind tunnels, computer design routines, and spray flow field modeling all assist a proliferant to build a more capable cruise missile.

Of the four major subsystems that compose a cruise missile—*airframe*, *propulsion*, *guidance, control, and navigation*, and *weapons integration*—none is expensive in and of itself, and a steady supply of each is available. In the late 1960's, the United States first introduced turbine *propulsion* systems that weighed less than 100 lb and produced many hundreds of pounds of thrust. These turbine engines, or their lineal descendants, powered most of the early U.S. cruise missile designs and were one of the least costly items. Depending upon the range a proliferant desires for its cruise missile, the powerplant may even be as prosaic as a reciprocating engine with a propeller. The latter, of course, has little hope of disguising its signature from defenses, but the mission profile may allow it to disguise itself as another platform. Even if no signature modification is considered, this type of missile has applications in regional wars where the technology of the defense is not as important as it is to an attacking proliferant.

Currently, GPS receivers provide more capability and accuracy than any targeting strategy requires of the *guidance, control, and navigation* subsystem. Cruise missiles, being aerodynamic vehicles, do not need the rapid response cycle time that ballistic missiles must have to keep the vehicle under *control* and on an appropriate track. Avionics systems available for first-generation commercial aircraft are both light enough and accurate enough to keep a cruise missile under control for long periods of time. For *navigation*, civilian code GPS is priced for the civilian hobbyist market, so purchasing an off-the-shelf navigation unit capable of obtaining 20 m of CEP is within the range of the common pocketbook. This level of accuracy is better than that of the early TERCOM systems installed on U.S. cruise missiles, which made them practical for the first time in the late 1970's.

For long cruise missile flight paths, a country without access to GPS systems must develop a mapping guidance logic for its cruise missile or accept highly degraded performance from an inertial measurement unit (IMU). A proliferant using one or two cruise missiles in an isolated attack from a standoff platform can achieve all of its targeting aims with an IMU, but long flight paths allow errors in the IMU to become so great that the missile may stray far from its target. Also, without an updated mapping system, the cruise missile must fly at an altitude high enough to avoid all manmade obstacles, thereby exposing itself to detection.

Even with GPS, the autonomous cruise missile carrying an on-board map must be supplied with the latest terrain and physical feature changes that have occurred along its course if it flies near the ground. Updated autonomous map guidance systems require large computer storage memories aboard the aircraft with units that can withstand the flight vibrations and possible thermal extremes of the missile over a long-duration flight. These units must be supplied with the latest maps that the delivering nation can obtain. Few nations have the space flight vehicles or high-altitude aircraft to build radar maps from overflights alone. Consequently, these maps will have to be purchased, or the proliferant will have to accept the attrition from missiles lost because of outdated information. The United States and Russia understand the key position that radar maps play in cruise missile guidance and are unlikely to allow the information stored in these maps to be released on the world market. Even if these maps are sold through some clandestine channel, they will quickly become outdated since cultural features change rather rapidly. As an alternative, a country may try to develop another guidance scheme, but the costs for developing a new infrastructure to support a map-based guidance system probably rivals that of the original TERCOM or a GPS constellation itself.

In the absence of GPS, the reliability of the cruise missile targeting philosophy becomes increasingly more problematic. As an alternative, a country may attempt to fly its cruise missile with radio guidance or other commands. Usually radio guidance uses frequencies high enough to operate only on line-of-sight reception. If the country expects to operate in hostile territory or attack at very long ranges, it must control the intervening repeater station to contact these missiles by real-time transmission of flight controls signals and position information.

Since cruise missiles fly relatively slowly and with only gentle accelerations, at the entry level, the *airframes* of these delivery systems can be built out of inexpensive aluminum of a grade as simple as 2024 - T1. Most proliferants with a basic metal production facility and an access to textbooks on metallurgy have a ready supply of this grade of aluminum. As proliferants design and build more sophisticated cruise missiles, they will undoubtedly substitute composite materials and other more elaborate structural elements in the airframe, but, for the most part, these materials are not needed.

A cruise missile airframe does not undergo particularly severe stress on its flight to a target, it does not pull any high "g" maneuvers, and it does not experience propulsion accelerations associated with gun or ballistic missile launches. Virtually any airframe that is structurally sound enough to be used in an ordinary airplane is adequate for a cruise missile. A designer can use factors of safety of 1.5 or 2 in the design to ensure structural integrity under all dynamic conditions without recourse to structural finite element computer codes, which generally only assist a designer to shave four or five percent from the weight of a design. Still, these technologies are included in the tables because their use does allow a proliferant to build a more capable cruise missile.

Technologies that advance the large serial production of inexpensive cruise missiles threaten current defenses built against missile attacks. These technologies include sheet metal processing machines that could form complex shapes, such as those found on the airframe or leading edge of cruise missiles; hydraulic presses or stamping mills that shape the nose cones or turbine inlets; and numerically controlled machines for parts production.

If a country wants to increase the penetrability of its cruise missiles, it must identify technologies that aid in signature reduction, signature masking, or other means to confuse detection systems. Some of these technologies include radar jamming and spoofing technologies; infrared suppression of engine exhaust; paints and coatings that disguise the thermal signature of leading edges; computer routines that predict the flow field around aerodynamic surfaces and the methods to change those surfaces to reduce heat transfer and turbulent flow fields; wind tunnel technology that supports the computer prediction; and computer routines that predict the RCS from a given geometry and predict redesign methods to achieve certain design specifications.

The cruise missile is suited for the delivery of chemical or biological agents if it does not fly at supersonic or transonic speeds. Most cruise missiles designed to fly at high speeds are not similarly able to fly at slow speeds without dramatic changes in the wing planform in flight. These changes in wing planform are generally not consistent with cruise missile geometries or packing volumes in the same way they might be in manned aircraft, such as the FB-111. Supersonic missiles generally cannot dispense chemical and biological agents from sprayers since the airstream itself will destroy the agent by heating or shock, but they do deliver nuclear weapons with great efficiency. None of these considerations are exclusive impediments to a proliferant's cruise missile development program. It is only a general guideline that high-speed cruise missiles make sense as a means to deliver nuclear weapons and low-speed cruise missiles are better suited for chemical and biological weapons.

Bomblets can also be included on transonic or supersonic missiles. These bomblets can be released over a target to ameliorate the airstream problem. After release, the bomblets decelerate, float to the target, and spray their agent into the air. Bomblets reduce the packing fraction of agent within the cruise missile airframe and, therefore, reduce the overall payload of a cruise missile. A subsonic cruise missile equipped with a sprayer dispensing agent from a single tank onboard the missile may simply release the agent into the airstream. In most cases, a large fraction of this agent will be destroyed before it reaches its target. To be more effective, the sprayer must dispense the agent so that it avoids the vortex from the tips of the wings and the disturbed airflow from the fuselage. Technologies that are required to develop bomblets, predict their flight path, or enhance the capabilities of sprayers as a means for a proliferant to deliver WMD from a cruise missile are highlighted.

Three key concerns of the cruise missile threat are (1) range extension to ranges greater than 500 km, (2) the ability to penetrate defenses, and (3) any technologies that reduce the cost of manufacture and therefore increase the size of a cruise missile inventory. In order of priority, the tables first list technologies that assist a country in building long-range cruise missiles. The tables then cover technologies that reduce the signature of a cruise missile and list those technologies that decrease the per unit cost or increase the total serial production of cruise missiles for a fixed price. Finally, the tables include support technologies that may make cruise missiles easier to use, package, or launch. As with each of the other delivery systems subsections, the tables are organized by specific subsystem of the aircraft: *airframe, propulsion, guidance, control, and navigation,* and *weapons integration.*

Cruise missiles differ from ballistic missiles as a potential threat because they share so many common technologies with existing vehicles that have been designed for other purposes. As a consequence, a proliferant can obtain much of the hardware to construct a cruise missile by cannibalizing existing commercial aircraft or by purchasing parts and components for the missile from legitimate suppliers. The technology tables serve only as a guideline to alert and inform export control regulators of general categories of technologies as opposed to specific performance specifications.

RATIONALE

Cruise missiles pose perhaps the gravest delivery system proliferation threat to U.S. worldwide interests. They are inexpensive to build and can, therefore, overwhelm current defenses by sheer numbers. They can be designed to be small with low-thrust engines and can penetrate radar and infrared-detection networks. The technology to build them is simple and available to any country that builds even rudimentary aircraft. Finally, since cruise missiles are unmanned, they require no flight crew training, expensive upkeep programs, special hangars for housing, or large air bases for basing. These factors make it especially difficult to collect intelligence on the development of indigenous cruise missiles and to anticipate the developing threat.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 1.3-1)

Systems

At least 12 exporting countries—Great Britain, the United States, China, France, Germany, Israel, Italy, Japan, Norway, Russia, Sweden, and Taiwan—have developed cruise missiles with some capability in the hands of proliferants to threaten U.S. worldwide interests.

Generally, these cruise missiles are small and have a limited range. While it is possible that they can be converted to deliver WMD, their short range limits their possible targets of interest. They may deliver biological or chemical agents against ports and airfields in regions of concern such as the Persian Gulf, but are not able to attack longer range targets. In addition, cruise missiles, such as the Chinese Silkworm, have many other limitations besides short range that restrict their utility as a WMD delivery system. The missiles leave a turbulent airflow in their wake, which makes it difficult to deliver a sprayed pathogen or chemical agent cloud. They fly along a predictable path towards the target rather than one that can realign itself to match the geometry of the target.

The following cruise missiles are a sample of missiles that are available legitimately on the world market and pose less threat as possible candidates for conversion to WMD delivery: the British Sea Eagle, the Chinese Seersucker and Silkworm, the French Exocet, the German Kormoran, the Israeli Gabriel, the Italian Otomat, the Japanese SSM-1, the Norwegian Penguin, the Soviet SSN-2C and its derivatives, the Swedish RBS-15, the Taiwanese Hsiung Feng 2, and the U.S. Harpoon. Older missiles, such as the Silkworm, have cumbersome and slow-moving control surfaces that do not readily adapt to the improvement in position calculation that GPS provides. Moreover, their guidance systems are intended mostly for the missiles in which they are placed and have little transference to a new airframe if they should be cannibalized. In most cases, the ease with which a cruise missile can be built leads a proliferant to build a new missile from scratch rather than attempting to adapt these older missiles for WMD delivery.

Even if the missiles do not pose a significant threat against U.S. worldwide interests, some aspects of their manufacturing base may migrate to more capable missiles and require close scrutiny. Missiles that contain small turbojet engines can be cannibalized, and the engines can be used in more threatening applications. A proliferant can also glean the knowledge to build these turbojets by reverse engineering the engines or setting up indigenous co-production facilities. Examples of exported missiles with small turbojet engines include the British Sea Eagle and the Chinese HY-4. Israel is offering an upgraded Gabriel, which features the latest in propulsion technology, to overseas customers. Other missiles in this class include the U.S. Harpoon, the

Swedish RBS-15, the Soviet SS-N-3, the Soviet SS-N-21, and the Otomat Mark-II. Cruise missiles that have immediate application to nuclear, chemical, and biological delivery include the U.S. Tomahawk and ACM, the Russian SSN-21, the AS-15, and the French Apache.

Harpoons have been exported to 19 countries, including Egypt, Iran, Pakistan, South Korea, and Saudi Arabia. India has received Sea Eagles, while Egypt, Iraq, Iran, Pakistan, and North Korea have Silkworms and Seersuckers, a version of which North Korea now manufactures. Italy has Kormorans, and Taiwan, South Africa, Chile, Ecuador, Kenya, Singapore, and Thailand have Gabriel Mark-IIs. Italy has exported turbojet powered Otomats to Egypt, Iraq, Kenya, Libya, Nigeria, Peru, Saudi Arabia, and Venezuela, while the Swedes exported the RBS-15 to Yugoslavia and Finland. In addition, the Soviets sold the long-range (500 km, 850 kg) turbojet powered "Shaddock" to Syria and Yugoslavia. At the next notch down in technological capability, the Soviets have flooded the world market with 1960's-generation liquid-fueled "Styx" (SS-N-2C) missiles. Algeria, Angola, Cuba, Egypt, Ethiopia, Finland, India, Iraq, Libya, North Korea, Somalia, Syria, Vietnam, Yemen, and the former Yugoslavia have the Styx missile in their inventories.

As the list of customers for the Styx demonstrates, the cost of a cruise missile is within the financial resources of even the most basic defense budgets. Even highly capable cruise missiles such as the Tomahawk only cost around $1.5 million per copy. This cost reflects the most advanced avionics systems and TERCOM guidance. At least one congressional study has shown that with the substitution of GPS, a proliferant could build a cruise missile with a range and payload capability roughly equivalent to the Tomahawk, for about $250,000. Unlike production of the heavy bomber, many countries have the economic resources and technical base to produce this kind of delivery system indigenously.

Subsystems

Though the sale of complete systems on the world market is a concern, that threat is much smaller than the possibility that a country could indigenously design and build a capable cruise missile by cannibalizing other systems for parts it cannot build on its own. Of particular concern are components and parts that reduce the cost of the missile in serial production, reduce the cost of position mapping navigation systems, and increase the range of these missiles.

Navigation and guidance continues to be the pacing item in threatening cruise missile development. The Standoff Land Attack Missile (SLAM) is a derivative of the Harpoon and contains in its nose a video camera that acts as a terminal guidance system. If a proliferant adopts this technology and can position a transmitter and receiver within line-of-sight to the missile from anywhere in the theater, it can dispense with the need for any other kind of guidance system. Israel has developed a capable guidance system that can be used in this application.

The next major subsystem component that enhances the capability of a cruise missile is the powerplant. The United States pursued the cruise missile long before the development of the first lightweight engine technology, so this is not a critical path item towards developing a cruise missile. Still, more capable engines increase the threat of a cruise missile. First, they reduce the RCS of the missile. Next, they increase the range by reducing the drag and power required for control surface actuation. Finally, they reduce other flight signatures, such as infrared cross-section and acoustic emission, that might be exploited in a defense network.

Country	Airframe		Propulsion			Guidance and Control			Weapons Integration	
	Control Surface Actuators	High Wing Loading Aerody-namic Designs	High Thrust-to-Weight Jet Engines	Small Turbine Engines	Advanced High-Energy Fuels	Radar Maps to Support Terrcom	Digital Topograph-ical Maps to Support GPS	Dynamic Test Equipment	Sprayers Adapted to Airstream	Small Nuclear Weapons
Argentina	♦♦	♦♦	♦♦	♦♦	♦♦	♦	♦♦	♦♦	♦♦♦	♦♦♦
Brazil	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦	♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦
Canada	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦
Chile	♦	♦♦	♦	♦♦	♦	♦	♦	♦	♦♦♦	♦
China	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Egypt	♦♦	♦♦	♦♦	♦♦♦	♦♦♦	♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦
France	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Germany	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
India	♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦	♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦♦
Iran	♦♦	♦♦	♦	♦♦	♦♦♦	♦	♦♦	♦♦	♦♦♦	♦♦
Iraq	♦♦	♦♦	♦	♦♦	♦♦♦	♦	♦♦	♦♦	♦♦♦	♦♦♦
Israel	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Italy	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦
Japan	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Libya	♦	♦	♦	♦	♦♦♦	♦	♦	♦	♦♦	♦
North Korea	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦	♦♦♦	♦♦	♦♦♦♦	♦♦♦♦
Pakistan	♦♦	♦♦	♦♦	♦♦	♦♦	♦	♦♦♦	♦♦	♦♦♦	♦♦
Russia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
South Africa	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦♦
South Korea	♦♦	♦♦	♦♦	♦♦	♦♦	♦	♦♦♦	♦♦♦	♦♦	♦♦♦
Sweden	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦
Syria	♦	♦	♦	♦	♦	♦	♦	♦	♦♦	♦
Taiwan	♦♦	♦♦	♦♦	♦♦♦	♦♦	♦	♦♦	♦♦♦♦	♦♦	♦♦♦♦
Ukraine	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United Kingdom	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United States	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦

Legend: Sufficient Technologies Capabilities: ♦♦♦♦ exceeds sufficient level ♦♦♦ sufficient level ♦♦ some ♦ limited

Because two or more countries have the same number of diamonds does not mean that their capabilities are the same. An absence of diamonds in countries of concern may indicate an absence of information, not of capability. The absence of a country from this list may indicate an absence of information, not capability.

Figure 1.3-1. Cruise Missiles Foreign Technology Assessment Summary

Table 1.3-1. Cruise Missiles Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
AIRFRAME					
CFD design optimization routines	PC and workstation codes that optimize physical properties such as vehicle weight per payload	CCL EAR 99; MTCR 16	None identified	None identified	Operating systems for high speed computers that reduce repeated instruction set calls to the CPU
CFD inverse design routines	PC and workstation codes that generate NC machine tool instructions	WA Cat. 2D; CCL Cat. 2D	None Identified	High-speed computing facilities or parallel processor operating systems	Operating systems for high speed computers that reduce repeated instruction set calls to the CPU
Finite element structural computer routines	PC-based routines capable of making more than 1,000 node calculations and containing automatic mesh generators	CCL EAR 99	None Identified	High-speed computing facilities or parallel processor operating systems	Operating systems for high speed computers that reduce repeated instruction set calls to the CPU
Hydrodynamic computer routines	Codes with automatic equations of state calculations	CCL EAR 99; MTCR 16	None Identified	High-speed computing facilities or parallel processor operating systems	Operating systems for high speed computers that reduce repeated instruction set calls to the CPU
Fluid mechanics finite element routines	PC based routines with mesh generators and Lagrangian logic	CCL EAR 99	None Identified	High-speed computing facilities or parallel processor operating systems	Operating systems for high speed computers that reduce repeated instruction set calls to the CPU
Metal stamping equipment	Capable of forming fuselages and leading edges in metal of 0.020 in. thickness or less	CCL EAR 99	None Identified	None identified	None
Composite filament-winding equipment	Two or more coordinated axes	MTCR 6; CCL Cat. 1B; WA Cat. 1B	None Identified	None identified	NC head control for winding patterns
Composite tape-laying equipment	Two or more coordinated axes	MTCR 6; CCL Cat. 1B; WA Cat. 1B	None Identified	None identified	NC feeder controls

(cont'd)

Table 1.3-1. Cruise Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Composite weaving or interlacing equipment	Two or more coordinated axes	MTCR 6; CCL Cat. 1B; WA Cat. 1B	None Identified	None identified	NC feeder controls
Radar absorbing material	Material that reduces complete design RCS by more than 10 dB	USML XIII; MTCR 17	None Identified	Radar ranges	Radar signal return prediction software
Structurally efficient radar absorbing material	Coatings and structural shapes that add less than 10% to the gross lift-off weight of an air vehicle	USML XIII; MTCR 17	None Identified	None identified	None identified
Aerodynamic design concepts which reduce IR signature	IR reduction paints and coatings	USML XIII; WA ML 17	Low latent heat of vaporization dopants and additives	None identified	None identified
Flow instrumentation	Sensors, and data acquisition equipment capable of measuring 2 kHz or higher signals in wind tunnels	WA Cat. 9B; CCL Cat. 9B	None identified	Sample and hold data acquisition boards for small computers	Data reduction from sample and hold boards
Innovative flow effectors	Adequate control power for vehicle range and speed improvement; lateral (directional) control without vertical stabilizers	MTCR 10; USML IV	None identified	None identified	None identified
PROPULSION					
Turbofan engines	Lightweight engines with bypass ratios greater than 6% and weights below 400 lb	MTCR 3; USML VIII	None identified	None identified	None identified
Turbojet engines	High thrust-to weight ratio engines (5:1) with weights below 400 lb	MTCR 3; USML VIII	None identified	None identified	None identified
Ramjet engines	Ramjet engines weighing less than 1,900 lb	WA Cat. 9A; MTCR 3; USML VIII	None identified	None identified	None identified
Small solid rocket engine for takeoff assistance	Motors weighing less 100 lb with thrust in excess of 1,000 lb	USML IV	High specific impulse solid rocket fuels and burn rate enhancers	Rocket motor test stands	None identified

(cont'd)

Table 1.3-1. Cruise Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
GUIDANCE, CONTROL, AND NAVIGATION					
Digital radar maps	Digital representations of the Earth's surface with height resolution <=20 m	MTCR 11; USML XI	None identified	Methods to measure radar images of the Earth's surface	Data compression software
Digital topographical maps	Digital representations of the Earth's surface with height resolution <= 20 m	MTCR 11; USML XV	None identified	Over the counter high resolution digital topographical maps	Data compression software
GPS receivers	Receiver capable of reducing civil use code signals to position and velocity within 50 msec	MTCR 11; USML XV; WA Cat. 7A; CCL Cat. 7A	None identified	None identified	C/A code ionosphere correction algorithms. C/A code geoid correction algorithms. Operational receiver software which prevents velocity and altitude limitations. Precision (P) code decryption algorithms.
Stellar optics	Equipment and hardware supporting daylight stellar observations with better than 1 microradian resolution	MTCR 9; USML XV	Low chromatic aberration lenses and specialized optical coatings	Optical test benches capable of calibration to within 0.1 microradian; methods to coat optical surfaces	None identified
Other guidance set design and radio inertial guidance	Any complete system or subset with 10 km or less accuracy at a range of 300 km, or 3.33% or less of range over 300-km range	MTCR 2, 9; USML XV	None identified	Instrument test range	None identified
Propulsion/airframe/ flight control system integration	Time control along with vehicle trajectory control to provide accurate location information along mission flight path	MTCR 9; WA ML 11; USML VIII, XV	None identified	Six degrees of freedom computer models	Source code for CAD/CAE
Vibration test equipment using digital control techniques	Equipment providing vibration at 10 g rms. between 20 and 20,000 Hz	MTCR 15; CCL Cat. 9B; WA Cat. 9B	None identified	Sample and hold data acquisition boards for small computers	Software capable of 4 times oversampling at 20,000 Hz
WEAPONS INTEGRATION					
Weapons separation design and prediction	Aerodynamic and trajectory prediction codes validated to within 1% of measured properties	MTCR 2, 16; USML XV	None identified	High-speed computing facilities or parallel processor operating systems	None identified
Submunitions separation or dispensing mechanisms	Submunitions with packing densities exceeding 75%	WA ML 4; USML IV	None identified	None identified	None identified

(cont'd)

Table 1.3-1. Cruise Missiles Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Biological sprayers	Specially designed airstream independent sprayers with nozzles and tankage to maintain live agent viability, with a dissemination efficiency of 10% or greater	USML XIV	None identified	Wind tunnels	None identified
Chemical sprayers	Specially designed airstream independent sprayers with a dissemination efficiency of 10% or greater	USML XIV	Corrosion-resistant materials	Wind tunnels	None identified
Advanced state vector calculation routines	Codes with validated results that predict submunition bomb case and aero glide vehicle variables within 1% of measured variable	WA ML 21; USML XXI	High-speed computing facilities or parallel processor operating systems	None identified	None identified

Table 1.3-2. Cruise Missiles Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
AIRFRAME			
CFD design optimization routines	Multivariate optimization procedures and their implementation	All flight vehicle structures	Parallel processors for PCs and work stations
CFD inverse design routines	Manufacturability and potential alternatives of design code solutions	Nozzles, turbine blades, and other complex components of cruise missile systems	Parallel processors for PCs and work stations
Finite element structural computer routines	Mesh generation and element geometry and dimensional parameters	Warhead lethality calculation	Parallel processors for PCs and work stations
Hydrodynamic computer routines	Proper solution of the energy balance in state change calculations	Effective delivery of chemical and biological weapons	Parallel processors for PCs and work stations
Fluid mechanics finite element routines	Simultaneous solution of Navier Stokes equations	Meteorology studies for effective delivery of chemical and biological weapons	Parallel processors for PCs and work stations
Metal-stamping equipment	None identified	Production of any vehicle parts that have military applications such as TELs	Conventional sheet metal brakes used with less complex shapes
Spin, flow, and shear forming machines	Proper laminar flow control of material	Nozzle and inlet manufacture	Composite technology and materials
Composite filament-winding equipment	Control of winding tension and material supply	Missile airframe manufacturing	Metal fuselages
Composite tape-laying equipment	Control of material feed tension	Control surfaces	Metal fuselages
Composite weaving or interlacing equipment	Geometric and elastic uniformity of supply material	Control surfaces	Metal fuselages
Radar-absorbing material	None identified	Low observables or stealth applications	None identified
Structurally efficient radar absorbing structure	Maintaining reasonable factors of safety—fuselage, wing at high stress points	Any combat air vehicle	None identified
Aerodynamic design concepts which reduce IR signature	Maintaining proper aerodynamic properties under all flight conditions and speeds	Any combat air vehicle	None identified
Flow instrumentation	Calibration and measurement readings in a dynamic environment	Any combat air vehicle	Less capable wind tunnels

(cont'd)

Table 1.3-2. Cruise Missiles Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Innovative flow effectors	Vehicle 3-axis stability and control with minimal cross-coupling	Increased range, maneuverability, and survivability	Traditional vertical tail configuration
PROPULSION			
Turbofan engines	Inefficiency of low-level cruise flight	High- level cruise missile applications	Turbojets, ramjets, internal combustion engines
Turbojet engines	Long flights increase stress and temperature levels on engines—lowers thrust	Better engine performance during long flights	Turbojets, ramjets, internal combustion engines
Ramjets	Initial boost to achieve ramjet operating speed	Surface-to-surface missiles	All other cruise missile technology
Small, solid rocket engine for takeoff assistance	Achieving high grain burn rates to accelerate a cruise missile without nozzle erosion or high stress on the missile	Longer range, more reliable	Air drop from large-capacity airplanes
GUIDANCE, CONTROL, AND NAVIGATION			
Digital radar maps	Making the original radar maps from satellite or other overhead surveillance methods	Autonomous guidance of aircraft	GPS guidance
Digital topographical maps	Resolution of maps to achieve flight through high relief terrain, cities, or other cultural clutter	Land-based autonomous navigation	GPS guidance
GPS receivers	Correcting civil use code to protected use code by numerical calculation of ionosphere correction	Any application requiring precise position knowledge	GLONASS receivers
Stellar optics	Multiple azimuth shots of known stars without interference of other bodies	Night-time azimuth sightings for artillery pieces or missile firing tables	None identified
Other guidance set design and radio inertial guidance	Communication with the moving platform to make real time corrections	Autonomous ship and tank navigation	Inertial, positional, or way point guidance
Propulsion/airframe/flight control system integration	Alignment of the guidance set within the airframe and calibration of the control corrections	High-performance air vehicles	None identified

(cont'd)

Table 1.3-2. Cruise Missiles Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Vibration test equipment using digital control techniques	Digital control of shakers and other equipment	Environmental testing of equipment in high vibration environments	Extensive flight testing
WEAPONS INTEGRATION			
Weapons separation design and prediction	Flight and mechanical properties prediction	Effective dispersal of weapons	Extensive flight testing
Submunitions separation or dispensing mechanisms	None identified	Effective dispersal of weapons	Cold gas thrusters; extensive flight testing
Biological sprayers	Keeping the agent from coagulating or breaking up in the wake of the delivery vehicle	Effective sprayers for any platform	Bomblets or other dispensers that disperse agent after the release from the cruise missile
Chemical sprayers	Keeping the agent from coagulating or breaking up in the wake of the delivery vehicle	Effective sprayers for any platform	Bomblets or other dispensers that disperse agent after the release from the cruise missile
Advanced state vector calculation routines	Numerical integration algorithms	Flight path prediction for cruise missiles	Way point flight with many vehicles

SECTION 1.4—COMBAT FIXED-WING AIRCRAFT

OVERVIEW

The Combat Fixed-Wing Aircraft subsection addresses the technologies that a nation needs to deliver a WMD by an aircraft. Unlike the cruise and ballistic missile subsections, which describe the additional burden a country may face to build the delivery system, this discussion assumes that most proliferants already possess aircraft or can purchase them legitimately on world markets.

Three key attributes of an aircraft pose the greatest threat: (1) reliable delivery of WMD, (2) ability to penetrate defenses, and (3) all-weather, day and night capability. The aircraft subsection describes and lists those technologies that allow a proliferant to carry out a targeting objective. The tables first list technologies that assist a country in weaponizing its aircraft fleet to accept WMD. Then they cover technologies that enable all-weather, day and night aircraft operations. Finally, the tables address the hardware and technical expertise that are needed to assist in penetrating defenses. Each of the tables is organized to categorize technologies, or adaptation of technologies, under the specific subsystem of the aircraft: *airframe, propulsion, guidance, control, and navigation*, and *weapons integration.*

Proliferants can pursue at least four technological advances to manned aircraft: (1) methods to increase range, (2) methods to weaponize WMD for reliability, (3) methods to mask or otherwise disguise flight signatures to detection networks, and (4) methods to launch an aircraft attack around the clock and in all-weather conditions.

Highlights

- The widespread sale of manned aircraft throughout the world reduces the need for a proliferant to build its own aircraft to deliver WMD.
- Existing aircraft can be modified to increase their range. In-flight refueling offers the best method to greatly extend aircraft range.
- All-weather, round-the-clock WMD delivery with manned aircraft is a significant threat.
- Technologies that assist a proliferant to acquire glide, terminally homed, and aerodynamically steered bombs can threaten U.S. worldwide interests.
- Existing and readily available avionics, autopilots, and navigation units are compatible with WMD delivery from manned aircraft.

Methods to Extend Range

All the identified proliferants maintain some manned aircraft systems. As total delivery systems, any of these aircraft can carry and drop almost any nuclear, chemical, or biological payload that the proliferant is capable of making or purchasing. Proliferants that possess limited-range aircraft have already begun to upgrade the severity of threat these aircraft pose by investigating the world market for in-flight refueling capability. In 1987, Libya purchased in-flight refueling tankers that are capable of extending the range sufficiently to strike European targets. Libya's only impediment to expanding its aircraft range is the availability of interim staging bases from which the tanker aircraft can fly.

Because of the physical isolation and political posture of many proliferants, few, if any, countries will act as host for proliferants to stage refueling tanker aircraft that could aid any WMD strike against U.S. worldwide interests. To do so would invite retaliation from the United States and the probable loss of the asset to U.S. counterforce operations. Given this geographical constraint, a proliferator may undertake to make modifications to an existing aircraft to extend range without in-flight refueling.

To accomplish any range extension to its aircraft fleet, the country must add additional fuel tanks, reduce the aerodynamic drag, or change the propulsion system to consume less fuel. Modifications to the *airframe* or *propulsion* subsystem of an aircraft may augment its range at the margins, but none of the realistic modifications a proliferant might make add to the range in the same dramatic way that an in-flight refueling capability does. Thus, if sales of in-flight refueling aircraft are limited and the use of foreign airfields for tanker traffic are monitored, the WMD aircraft threat can be limited to a regional theater of operation. The technology tables have been organized to highlight these considerations.

Methods to Increase Targeting Reliability

With a manned crew, targeting reliability is expected to be high. In the event of any problems en route to the target, the crew may be able to take action to change its target. Similarly, most manned aircraft crews usually visually confirm the position of a target (except when dropping stand-off weapons, such as cruise missiles). *Guidance* and *navigation* subsystems are important to aid in navigation to the target. Significant errors in targeting occur from unpredictable winds, incorrect fuzing information, or poor aerodynamic design. The proper *weapons integration* of WMD warheads can eliminate most of these problems.

An aircraft can often be tracked and shot down by existing defense batteries. At some point, a proliferant aircraft will likely display itself to any tracking sensor as it approaches a target. A proliferant aircraft may, however, delay this detection to radar tracking networks by following contours in the terrain and by employing electronic countermeasures. Neither of these two changes requires modifications to the aircraft's propulsion or airframe and, therefore, they take less effort.

Aircraft can be flown to the target using only visual cues if meteorological conditions permit. A technology that allows an aircraft to operate in any weather condition or during any time of the night or day greatly enhances the threat this delivery system poses. In addition, if a technology allows an airplane to fly outside of its normal operating environment, while following the contours of the terrain, the aircraft then complicates defense strategies. Some technologies that can be fitted onto aircraft to accomplish these objectives are (1) an avionics unit that senses position and position rate; (2) small onboard computers capable of automated flight planning, targeting, en route navigation, and ensured terrain avoidance; and (3) addition of stealth.

Many flight-qualified control systems produce sufficient force (sometimes known as command authority) and response time (or phase margin) to steer any existing aircraft autonomously. These actuators must be coupled to a flight computer, which detects position and position rates and compares them to an on-board stored radar or topographical map of the terrain. In a fully autonomous system, the flight computer must predict the course far enough in advance to give the aircraft time to maneuver and avoid any obstacles within performance constraints, such as climb rate and roll rate. Complete guidance and control subsystems and the components that comprise them are sufficient technology to constitute a proliferation threat.

Methods to Increase Attack Flexibility

Navigation systems traditionally compare either analog or digital representations of the Earth's surface to the radar or topographical scene through which the airplane flies. In recent years, these computers have relied almost exclusively upon digital representations. While reversion to an analogue scene comparison is not ruled out, digital maps are by far the most militarily threatening. They have better resolution, are more accurate, and are updated frequently by contractors, which removes from the proliferant the burden of generating the databases for these maps. Computers that support digital navigation and scene generation require highly sophisticated storage devices and rapid random access to the stored information.

Methods to Increase Penetration

Once an aircraft is within range of defense radars, it may use electronic countermeasures in several ways to spoof defense assets. Sophisticated countermeasures may alter the signal returned to the defense radar to make the aircraft appear to be some other type of aircraft. This technique is especially effective against radars that present thematic rather than actual RCSs to defense personnel evaluating the surroundings. Simpler electronic countermeasures may make an aircraft appear to be much larger or spread out over a greater region of the sky. Consequently, hit-to-kill interceptors may miss the actual aircraft as they fly to intercept the large region within the predicted target area. A proliferant's electronic countermeasures may not prevent the aircraft from being ultimately targeted and eliminated, but they delay the interception to allow the aircraft to release its weapon on the actual target or an adjacent target of near equivalent value. As a result, electronic countermeasures are listed as an important technology to be denied to proliferants.

As a last resort, a proliferant may attempt simply to overwhelm the defense by saturating a target with too many aircraft to intercept. This is a less attractive alternative with aircraft than it is with cruise missiles because of the high cost of purchasing the aircraft, maintaining them, and training a capable crew. Moreover, since a proliferant cannot predict which aircraft will penetrate and which will be intercepted, it must equip all of them with WMD. For chemical and biological agents, this may not be too difficult, but few proliferants can currently manufacture nuclear weapons in sufficient quantities to threaten a saturation attack.

All aircraft require *weapons integration*, whether they arrive at the point of sale in their weaponized state or not. Indigenously produced WMD will probably differ from their foreign counterparts. A proliferant must discover, on its own, the idiosyncrasies of the interaction of a weapon and the aircraft that carries it to plan for these modifications. For example, bomb bay doors opening at certain velocities sometimes cause severe aircraft vibration. Similarly, once the bomb bay doors are open the airflow around the weapon may cause it to vibrate uncontrollably. Again, modern computational fluid dynamics (CFD) codes and their aerodynamic equivalents streamline the redesign process to achieve clean stores separation under all circumstances. Wind tunnels assist a proliferant in estimating the extent of any needed modifications.

The weapons, on the other hand, may need to undergo significant refinements, depending on the ultimate intentions of the country. Some simple standoff weapons, such as glide bombs, may provide a proliferant a unique penetration capability. As an example, a country can target its neighbor without violating its airspace by using a glide bomb that has a lift-to-drag ratio of 5 and dropping it from an aircraft operating at a ceiling of 50,000 ft. The girth of the weapon or its aerodynamic surfaces may create a release problem that forces the proliferant to consider designing folded aerodynamic surfaces. However, a glide bomb is both more accurate than an ordinary gravity bomb and has a greatly reduced RCS compared to the aircraft which drops it, thus solving many of the problems of penetration.

To hit in the vicinity of the target, even a large area target such as a city, the post drop vehicle may need an autonomous guidance and control unit. This unit does not need to meet the specifications of a missile-grade IMU, but it must be good enough to provide simple feedback control to the aerodynamic control surfaces. Systems for aircraft using GPSs are being made available on the world market. Many European and U.S. manufacturers make avionics equipment that can control a split flap or simple aileron.

The tables include technology items directly tied to accurate aerodynamic bombs, control surfaces for a bomb, and steerable aerodynamic devices suitable for releasing airborne agents.

RATIONALE

Fixed-wing aircraft used for the delivery of WMD are of significant concern. Most potential proliferants have reasonable numbers of tactical aircraft and have trained pilots to fly them. The aircraft available usually have a short strike range, suitable for their limited geographical area. Longer range capability, while possible with modifications to existing aircraft and the development of in-flight refueling capabilities, involve introduction of new technologies and systems.

With the advent of the GPS, proliferants now have a technique to improve the navigational capability of their aircraft significantly. Also, even though state-of-the art signature reduction is not readily available, more conventional countermeasures would still be of considerable value, particularly in regional conflicts.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 1.4-1)

Systems

Since the end of the Cold War, widespread sales have been made of aircraft capable of delivering WMD. China owns SU-27 Flankers, and North Korea has SU-25 Frogfoots. Syria and Libya possess SU-24s, and Iraq, at one time, had the Mirage F1-C. India has 15 Jaguars. The SU-24 has a combat radius of 1,000 km, giving it the most threatening range capability in a regional conflict. However, since they can trade payload, speed, fuel, and range, any of these aircraft can execute a WMD delivery.

Effective use of aircraft in a combat role requires ongoing training, maintenance, and functioning of a substantial infrastructure. Key needs include trained people, availability of spare parts, and realistic exercises. The case in which Iran lost U.S. support is instructive in the limits to keeping aircraft viable as a means of delivery.

China, India, Pakistan, and Israel can maintain and support a tactical aircraft infrastructure, train and recruit pilots, and sustain their aircraft in a threatening posture. North Korea has great difficulty in training pilots and maintaining its aircraft but could mount a single attack against South Korea with its SU-25 Frogfoots. As the Gulf War showed, when the coalition achieved air supremacy, Iraq did not mount even a single sortie against a coalition target, and in all likelihood Iran is in similar straits. Syria has the ability to maintain its aircraft with foreign assistance from either the former Soviet Union or elements of the former Soviet Bloc. The United States has no way of limiting this assistance as it did in post-Revolutionary Iran because its does not control the market for parts and personnel relevant to the air fleet.

All members of the G-7, Sweden, and Poland can supply technical expertise and maintenance personnel to proliferants. South Africa or its agents can funnel spare parts for aircraft to proliferants facing severe shortages. Former Cold War enemy production entities have created licensed co-production facilities for aircraft in China, Israel, South Africa, South Korea, Taiwan, and other countries. Any of these facilities can produce some parts of interest to a proliferator. Many other newly industrialized countries—including Argentina, Brazil, Chile, and Egypt—produce indigenous whole aircraft. A country with an indigenous aircraft production capability may supply custom-made parts or reverse engineered replacement parts for grounded aircraft.

Subsystems

Because of the ubiquity of the aircraft industry in the United States, Russia, and many other countries, virtually every nation in the world has available to it tactical aircraft (or civil aircraft of equivalent range and payload capacity) through legitimate purchase. Smaller aircraft, such as business jets and jet trainers, sold overtly to proliferants can be cannibalized for subsystems, particularly navigation and control subsystems. As a result, no proliferant has a compelling need to build an independent, indigenous aircraft industry solely for delivering its WMD by aircraft. In fact, because of the availability of suitable aircraft on the world market, such an independent capability would be a waste of resources and draw funds away from other needs. A proliferant pursuing aircraft delivery systems needs only the capability to make modest modifications to existing military or civilian aircraft, including bomb bays or bomb racks, associated weapons initiation systems, and research flight conditions for delivering weapons.

To complete the stockpile-to-target delivery cycle at the subsystem level, a proliferant needs to build and test the WMD device that will be delivered by aircraft. Every nation of the FSU, with the exception of Bulgaria, has a trained work force and either existing wind tunnels or structural dynamics laboratories capable of required testing. In the former Yugoslavia, parts of this infrastructure are scattered about the various component states, with most of the research laboratories concentrated in Croatia and Slovenia. India has similar facilities and a tradition of education that can adapt the facilities to unconventional design concepts. The Baltic Republics can perform R&D into flight dynamics and have computer facilities available that can host 1980's vintage U.S. software for advanced structural designs. The industrialized nations of South America (Argentina, Brazil, and Chile) are capable of either building comparable facilities indigenously and performing experiments and analyses for a third party or exporting the technical talent to build such facilities elsewhere.

These same entities can design and build a variety of warhead systems, consistent with tactical aircraft delivery, including aerial bombs, spray systems, glide bombs, terminally steered or guided bombs, and cruise missiles. These devices have the common requirement of aerodynamic flight through a defined mission profile. For chemical and biological weapons, the designer must also provide some mechanism for air braking the warhead, such as fins, or other glide devices that allow the warhead to disseminate agent over a broad area, and a method to keep biological agents in an active condition through the delivery cycle. Failing this, the proliferator must accept the greatly reduced efficiency from dissemination initiated by a burster charge.

At the most rudimentary level, a proliferator must produce an aerodynamic warhead configuration that has a repeatable and predictable flight profile, does not induce severe vibration from air stream buffeting, and can detonate at a predetermined altitude or upon ground contact. Iran, Iraq, Yemen, Indonesia, Bulgaria, the Czech Republic, Slovakia, the Baltic Republics, Pakistan, Mexico, and Cuba can design and build these weapons. Those capabilities that support or further weapon system design are included as "sufficient" technologies.

Country	Airframe		Propulsion		Guidance and Control			Weapons Integration		
	Modifica-tions to Comercial Aircraft	Low-Observable Modifica-tions to Existing Aircraft	Propulsion System	Advanced High-Energy Fuels	All-Weather Guidance and Flight Modifica-tions	Digitally Driven Acutators for Existing Autopilots	Military-Grade GPS Receivers	Bomb Sights	Simple Steered or Homed Bombs	Bomb Flight Mechanics R&D
Argentina	♦♦♦	♦♦	♦♦♦	♦♦	♦	♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦♦
Brazil	♦♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Canada	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Chile	♦	♦	♦	♦	♦	♦	♦	♦♦♦	♦♦♦	♦♦
China	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Egypt	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦
France	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Germany	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
India	♦♦♦	♦♦	♦♦♦	♦♦	♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦
Iran	♦	♦	♦	♦♦♦	♦	♦♦	♦♦	♦♦♦	♦♦♦	♦♦
Iraq	♦	♦	♦	♦♦♦	♦	♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦
Israel	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Japan	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Libya	♦	♦	♦	♦♦♦	♦	♦	♦	♦♦	♦♦	♦♦
North Korea	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Pakistan	♦♦♦	♦	♦♦	♦♦	♦	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦
Russia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
South Africa	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦
South Korea	♦♦	♦♦	♦♦	♦♦	♦♦	♦♦♦	♦♦♦	♦♦	♦♦	♦♦♦
Sweden	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Syria	♦	♦	♦	♦	♦	♦	♦	♦♦	♦♦	♦♦
Taiwan	♦♦	♦	♦♦	♦♦	♦	♦♦	♦♦♦♦	♦♦	♦♦	♦♦♦♦
Ukraine	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United Kingdom	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United States	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦

Legend: Sufficient Technologies Capabilities: ♦♦♦♦ exceeds sufficient level ♦♦♦ sufficient level ♦♦ some ♦ limited

Because two or more countries have the same number of diamonds does not mean that their capabilities are the same. An absence of diamonds in countries of concern may indicate
an absence of information, not of capability. The absence of a country from this list may indicate an absence of information, not capability.

Figure 1.4-1. Combat Fixed-Wing Aircraft Foreign Technology Assessment Summary

Table 1.4-1. Combat Fixed-Wing Aircraft Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
AIRFRAME					
Finite element structural computer routines	PC-based routines capable of making 1,000 node calculations and containing automatic mesh generators	USML VIII	None identified	High-speed computing facilities or parallel processor operating systems	Operating systems for high-speed computers that reduce repeated instruction set calls to the CPU
Fluid mechanics finite element routines	PC-based routines with mesh generators and Lagrangian logic	MTCR 16; USML VIII	None identified	Flow tables and hydro-dynamic test facilities that exploit the hydrodynamic similitude approximations to compressible flow; high-speed computing facilities or parallel processor operating systems	Operating systems for high-speed computers that reduce repeated instruction set calls to the CPU
Vibration shakers and other environmental test equipment	Vibration power spectral density output of 10 g rms. between 20 and 20,000 Hz, with forces >=50 kN (11,250 lb)	MTCR 15; CCL Cat. 9B	None identified	Piezoelectric force transducers and sample and hold data acquisition boards for computers; high-speed computers	Fourier transform, chirp, and other advanced signal processing software and modal analysis software
Aerothermal wind tunnels	Input heat flux levels >100 BTU/ft^2-sec	MTCR 15; CCL Cat. 9B; WA Cat. 9B	None identified	Hot wire anemometers or wind vector and stability devices with directional response <1 deg and time response <0.1 msec.	Finite element and hydrodynamic software
Conventional wind tunnels	Wind tunnels producing Reynolds Numbers in excess of 2.5 million per foot	MTCR 15; CCL Cat. 9B; WA Cat. 9B	None identified	None identified	None
Structural modifications for thrusted munitions release or glide vehicles with stored aerodynamic surfaces	Glide vehicles with L/D >5 or thrust missile with >0.1 km/sec velocity change	WA ML 4, 5; USML IV, XII	None identified	None identified	None identified
Propulsion/airframe/ flight control system integration	Techniques that provide tradeoffs on range, maneuverability, and safety with complexity and weight	MTCR 2, 9; USML VIII	None identified	Six degrees of freedom computer models	Source code for CAD/CAE

(cont'd)

Table 1.4-1. Combat Fixed-Wing Aircraft Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
In-flight refueling—receiver technology	Any technology level is reason for concern	WA ML 10; USML VIII	None identified	None identified	None identified
Innovative control effectors	Adequate control power for vehicle range and speed improvement; lateral (directional) control without vertical stabilizers	CCL EAR 99; USML XIII	None identified	None identified	None identified
Metal-stamping equipment	Capable of forming fuselages and leading edges in metal of .020 in. thickness or less	CCL EAR 99	None identified	None identified	None identified
Low observables external stores carriage	Structural design with RCS reduction >=3 dB over equivalent volume and give between 1 GHz and 30 GHz	WA ML 17; MTCR 17; USML XIII	Composites	None identified	None
Signature reduction techniques, IR and RF	RCS reduction of 10 dB or greater across frequency range of 1 GHz to 30 GHz; design and coatings for IR and radar signature reduction	WA ML 17; MTCR 17; USML XIII	Special polymers and fibers	Radar range, IR detectors	RCS, signal return prediction software
PROPULSION					
Turbofan engines	Lightweight engines with bypass ratios greater than 6%	MTCR 3; USML VIII	None identified	None identified	None identified
Turbojet engines	High thrust-to weight (6:1) engines	MTCR 3; USML VIII	None identified	None identified	None identified
Technology for high temperature and erosion protection coatings for engine parts	Temperature change through material >=150 °C/in.; erosion resisting technologies that insulate against temperature of >2,000 °C	WA Cat. 2; CCL Cat. 2	Ceramics (e.g., alumina and magnesia) and $ZrO_2 + Y_2O_2$	None identified	None identified
Inlets for transonic and low supersonic flight speeds	Inlet designs or modifications that reduce the ratio of shock standoff to inlet diameter or turning angle by no more than 10% at constant Mach numbers	CCL EAR 99	None identified	None identified	None

(cont'd)

Table 1.4-1. Combat Fixed-Wing Aircraft Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Propulsion integration for subsonic, transonic, and low supersonic flight speeds	Modifications to enable flight below 200 ft AGL	CCL EAR 99; USML VIII	None identified	Load and load rate force simulators to apply flight conditions to controls surfaces	None
Thermal spray forming equipment	Power levels >150 kW, gas velocities of 3,000 m/sec and spray rates of >15 kg/hr	CCL EAR 99	None identified	None identified	None Identified
GUIDANCE, CONTROL, AND NAVIGATION					
Digital radar maps	Digital representations of the earth's surface with height resolution <=20 meters	MTCR 11; USML XI	None identified	Methods to measure radar images of the earth's surface	Data compression software
Global Navigation System	Accuracy of <20 m. in position and <200 nano-seconds in time	MTCR 11; WA Cat. 7A; USML XI; CCL Cat. 7A	None identified	GPS signal simulators	Algorithms that use GPS signals to compute steering commands based on the flight characteristics of the bomber
Map guidance technology	Automatic terrain avoidance, efficient route planning and defense evasion hardware and software	MTCR 11; USML XI; WA Cat 7E; CCL Cat 7E	None identified	None identified	Data compression algorithms
GPS receivers	Receiver capable of reducing civil code signals to position and velocity within 50 msec	MTCR 11; USML XI; WA Cat. 7A; CCL Cat. 7A	None identified	None identified	Civil code to protected code calculation algorithms
Full authority flight control systems	Techniques to tradeoff stability, maneuverability and safety with complexity and cost	WA Cat. 9D, 9E; CCL Cat. 9D, 9E; USML VIII	None identified	Six degrees of freedom simulation combined with pilot in the loop	Source codes for control logic
Vibration test equipment using digital control techniques	Equipment providing vibration at 10 g rms between 20 and 20,000 Hz	MTCR 15; CCL Cat. 9B; WA Cat. 9B	Sample and hold data acquisition boards for small computers	Piezoelectric force transducers and sample and hold data acquisition boards for small computers	None identified

(cont'd)

Table 1.4-1. Combat Fixed-Wing Aircraft Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
WEAPONS INTEGRATION					
Weapons separation design and prediction	Aerodynamic and trajectory prediction codes validated to within 1% of measured properties	USML VIII	None identified	High-speed computing facilities or parallel processor operating systems	None identified
Advanced state vector calculation routines	Codes with validated results that predict submunition bomb case and aero glide vehicle variables within 1% of measured variable	WA ML 21; USML XXI	None identified	High-speed computing facilities or parallel processor operating systems	None identified
Submunitions separation or dispensing mechanisms	Submunitions with packing densities exceeding 75%	WA ML 4; USML IV	None identified	None identified	None identified

Table 1.4-2. Combat Fixed-Wing Aircraft Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
AIRFRAME			
Finite element structural computer routines	Mesh generation and element geometry and dimensional parameters	Needed for higher performance engines and airframes	Parallel processors for PCs and work stations
Fluid mechanics finite element routines	Simultaneous solution of Navier Stokes equations	Meteorology studies for effective delivery of chemical and biological weapons	Parallel processors for PCs and work stations
Vibration shakers and other environmental test equipment	Producing and measuring frequency response and relating the information to flight performance	High performance air vehicles	Expanded flight test program; subsystem and component testing
Aerothermal wind tunnels	Generating sufficient cooling and air replacement to prevent temperature change effects on measured parameters	Performance increases	Expanded flight test program and empirical design modifications
Conventional wind tunnels	Flow straightening and flow visualization of subsonic and supersonic effects	Range increase resulting from lower drag profiles for external munitions stores	Expanded flight test program and empirical design modifications
Structural modifications for thrusted munitions release or glide vehicles with stored aerodynamic surfaces	Predicting and correcting for flow field on bomb bay doors as they open to release munitions and external stores flow fields in flight	Increased reliability of delivery systems and munitions	Additional weight and aero-dynamic drag for struts, fillets, and other nonoptimum load-bearing surfaces
Propulsion/airframe/flight control system integration	Pilot acceptance; maintaining adequate gain and phase margins; incorporating response time in maneuver parameters	Increased range and maneuver performance	Pilot integration of parameters
In-flight refueling	Carry and deliver equipment; training and rehearsal of flight crews	Longer range offers more targeting opportunities	Drop tanks, extra fuel capacity tanks fitted in the fuselage
Innovative control effectors	Vehicle 3-axis stability and control with minimal cross-coupling	Increased range, maneuverability and survivability	Traditional vertical tail configuration
Metal-stamping equipment	Bending complex shapes in low modulus of elasticity materials	Higher production quantities	Simpler contours produced by conventional sheet metal brakes
Low observables external stores carriage	Reducing radar cross-section in a manner consistent with low drag profiles	Better radar penetration to allow aircraft to move closer to target and drop glide vehicle or cruise missile	Internal munitions storage at a decreased payload or volume
Signature reduction techniques	Adding materials and coatings that will not affect structural integrity or flight performance	All air vehicles	None identified

(cont'd)

Table 1.4-2. Combat Fixed-Wing Aircraft Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
PROPULSION			
Turbofan engines	Decrease in net thrust at low altitudes makes low level cruise fuel inefficient	Improved range and ceiling	Any propulsion unit consistent with range and payload needs, e.g., internal combustion engines
Turbojet engines	Thrust is dependent on the maximum stress and temperature levels the engine can sustain for long flights	Improved range and ceiling	Any propulsion unit consistent with range and payload needs, e.g., internal combustion engines
Technology for high temperature and erosion protection coatings for engine parts	Thrust is dependent on the maximum stress and temperature levels the engine can sustain for long flights	Increased reliability and improved range	Ceramics and carbon carbon inserts
Inlets for transonic and low supersonic flight speeds	Forming aerodynamically sound designs that do not choke	Increased range and better defense penetration	Increased drag and reduced range
Propulsion integration for subsonic, transonic, and low supersonic flight speeds	Upgrading existing airframes with more modern engines that may have higher thrust levels or improved fuel consumption	All air vehicles	None identified
Chemical Vapor Deposition (CVD) equipment	Manufacturing equipment maintenance to ensure reproducibility	Improved reliability	None identified
Thermal spray forming equipment	Maintaining thermal control and flow consistency	Improved reliability	None identified
GUIDANCE, CONTROL, AND NAVIGATION			
Digital radar maps	Reducing radar images to digital representations that can be stored and retrieved efficiently	Delivery of a munitions within a lethal radius	GPS topographical maps
Global Navigation System	Time required to calculate position and corrections to position to obtain desired flight path	Delivery of a munitions within a lethal radius	IMUs; radio controlled or preprogrammed flight profiles
Map Guidance Technology	Resolution of the surface of the Earth particularly in height in order to ensure all obstacles are cleared by the flight vehicle	Increased operations envelope to include night and all weather flight	More restrictive operational conditions
GPS receivers	Correcting civil code to protected code	Navigation	GLONASS receivers
Full authority flight control system	Maintenance of adequate gain and phase margins; adequate response time over flight envelope; redundancy vs. safety	Increased reliability and accuracy	Pilot integration of parameters
Vibration test equipment using digital control techniques	Properly shock isolating the test equipment so that test results are meaningful	Reliable weapons delivery	Flight testing under highly stressed conditions

(cont'd)

Table 1.4-2. Combat Fixed-Wing Aircraft Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
WEAPONS INTEGRATION			
Weapons separation design and flight prediction	Vibration and shock from interference with the main body both upon release and in a bomb bay or cargo hold with the doors open	Reliable weapons delivery	Flight test program to gather information empirically
Advanced state vector calculation routines	Prediction of non-linear effects from spinning and unsymmetrical parts within the weapon	Delivery within a lethal radius	Conventional bomb sights
Submunitions separation or dispensing mechanisms	Proper release under realistic conditions	Reliable weapons delivery	Flight test program to gather information empirically

SECTION 1.5—ARTILLERY

> ### *Highlights*
>
> - Artillery pieces for possible delivery of WMD exist in virtually every military organization in the world.
> - A proliferant must harden WMD shells against high spin rates and accelerations to use an artillery piece to deliver WMD.
> - Existing artillery pieces have insufficient range to allow a proliferant to use artillery as a strategic WMD delivery system except in special circumstances.
> - Nuclear warheads are difficult to fit into existing conventional artillery tubes.
> - Several proliferants have the technical capability to custom-build long-range guns, similar to the Iraqi Supergun, to deliver WMD.
> - Superguns are expensive and have limited sustained firing potential.
> - Use of Multiple Launch Rocket Systems overcomes some artillery limitations.

OVERVIEW

In the Artillery subsection, two military strategies for using artillery to deliver WMD are discussed. Traditionally, artillery has been a battlefield weapon rather than a long-range attack weapon, although the United States, Russia, France, and Britain have demonstrated that conventional artillery tubes can deliver nuclear, chemical and biological agents. Each of these countries had a specific battlefield application for WMD of the 30-km range. Few of the strategic, technical, economic, and political forces that led the superpowers to develop this highly specific capability apply to conditions within proliferants. However, artillery may be attractive to proliferants for other reasons, including the availability of designers and parts and the possibility that a WMD shell from one of the superpower's arsenals could suddenly become available.

As an indigenous product, artillery can be applied as a *strategic* WMD delivery system. Iraq demonstrated imaginative use of artillery in the large investment it made in the Supergun project. In this case, a proliferant chose to develop a strategic delivery system that happened to be a scaled-up version of a well-known artillery delivery system. These vastly different applications of the same basic technology show that a proliferant that pursues artillery as a means of delivery must choose either to use existing artillery pieces and solve the technical problems of designing a shell to accommodate these weapons or design a new weapon for the shell they intend to deliver. The United States, as an example of the former approach, built nuclear and chemical rounds compatible with their existing 155-mm guns. These shells had flight properties that exactly matched the flight properties of conventional ammunition. Iraq, as an example of the latter approach, built the Supergun specifically to fire a single, special nuclear round.

Using Existing Artillery Pieces

When a country can manufacture a WMD shell to exactly match a conventional round, it solves all of the technical problems of gun manufacture because many suppliers on the world market provide artillery pieces in standard 155-mm, 203-mm, and 406-mm caliber gun tubes. Still, the proliferator must solve unique technical problems associated with the WMD warhead.

Nuclear

To use existing artillery pieces, a proliferant must be sufficiently advanced in its nuclear design to make a warhead with a diameter small enough to fit a standard caliber tube. Consequently, to be used in a conventional tube, a nuclear round must match the inertial and aerodynamic properties of conventional shells and be able to withstand the acceleration produced by the firing charge and the high spin rates (up to 250 Hz) of modern artillery shells. If it does not closely meet these characteristics, the shell will suffer from poor range and accuracy.

Since nuclear shells have components made of high atomic-number materials and these materials are traditionally configured in a spherical shape, aeroballisticians must frequently add supplemental materials to match the mass of nuclear artillery shells and the ratios of the moments of inertia. Countries that have solved this problem have used highly dense materials, such as depleted uranium, as a ballast.

As an alternative, a country can ignore the question of range loss and high dispersion and accept reduced performance. Often, this means that their military can only fire the shell to its maximum range, and an extensive testing program is required to determine the limits of the dispersion. Since the surrogate shells used in this test program must inertially match the real nuclear rounds and a statistically meaningful test program requires many firings, the proliferator must have a ready source of high atomic-number (non-nuclear) material to use in its test rounds.

A nuclear-capable proliferant must also be able to build a nuclear round that can withstand the high acceleration produced by the firing charge. For example, in most full-range 155-mm rounds, the initial acceleration on the shell may exceed 10,000 g's. The proliferant that builds its nuclear shell indigenously must be able to form insensitive high explosives in complex shapes that resist cracking and spalling under these accelerations. They must also be able to build a special nuclear fuze, which differs from the fuze in a conventional round, and the fuze electronics that can withstand the acceleration and still perform normally at the end of the trajectory.

Since the aerodynamic shape of the shell must also match a conventional round, few, if any, changes can be made to overall shell design. If the artillery shells are made indigenously, the proliferant has the means to make any type of casing for a nuclear shell. For a nuclear shell, a proliferant can make one concession to the warhead when the shell must be stored for a long period of time. The designers may have to substitute a new outer casing material that is less sensitive to embrittlement from a low-level nuclear radiation environment.

Chemical

Since the specific gravity of most chemical agents is near to that of conventional high explosives, a chemical round for an existing artillery piece requires even fewer design concessions than a nuclear round. With only minimal ballasting, designers can match the inertial properties of chemical and conventional shells quite easily.

Because the materials involved have mid-range atomic numbers, ballasting can be made from many materials. In flight, though, chemical WMD, being a fluid, has a tendency to change its inertial properties because of the centrifugal force created by the spinning shell. Binary chemical agents take advantage of this spinning to mix the compounds. But the spinning momentum forces the fluid to migrate to the outer casing wall of the shell and alter the inertial properties in a way that conventional high explosives—most often being solid—do not. As the shell flies, this fluid migration has a tendency to cause large coning angles and increase the drag on the body.

Liquid migration is a function of many properties of the WMD, but the most important is the viscosity of the liquid. Proliferants may solve the variable inertial problem by modifying the viscosity of the liquid with liquid additives or by including internal baffles that dampen the motion of the liquid when the shell is fired.

The liquid material is fairly insensitive to the shock of firing and virtually no accommodation needs to be made for WMD rounds beyond that already made in conventional rounds. The fuzing and firing circuits of chemical rounds do not require the high energy and precise timing of nuclear rounds; thus, one can manufacture a high explosive detonator for an artillery shell and use this same detonator on a chemical round with little modification. Both chemical and biological rounds do require efficient dissemination mechanisms since the agents must be spread over a large area. Submunitions and the technologies that remove them from an artillery shell in flight and decelerate them or alter their flight path support the more efficient dispersion of agent. Radar fuzes or timers that can open a shell and release submunitions must have a firing precision of better than 50 ms to be effective.

Biological

Biological agents have properties similar to chemical agents and the design considerations for artillery shell delivery follow similar reasoning. Biological toxins generally withstand the shock of firing from an artillery tube with little degradation in performance. Live biological agents, on the other hand, degrade significantly when placed in this high acceleration environment. Virtually any proliferant that can manufacture an artillery shell for special purposes, such as incendiaries or flares, has all of the technological sophistication at its disposal to deliver biological toxins in this manner. On the other hand, the high acceleration experienced by all artillery shells means live biological agents are unlikely candidates for this means of delivery unless microencapsulation or other buffers are used to alter the susceptibility of the agent to shock. Spores of certain pathogens, such as anthrax, resemble toxins in their ability to withstand shock.

Most deliverable biological agents, however, have lower specific gravities than existing conventional rounds. The light weight of the biological material, which may include fillers, release agents, protective coatings, and agglutinating matter to accrete a respirable particle, requires a country to consider carefully means to ballast the shell to match the inertial properties of conventioanl rounds.

Ancillary Technologies Common to All Types of WMD

The two technical hurdles that must be overcome to use WMD in artillery shells—protection against acceleration and matched inertial properties—can be replicated in a laboratory setting or simulated on a computer. Flight trajectory prediction programs with 6-degree-of-freedom modeling will reveal to an analyst the degree of uncertainty in a shell's flight path when inertial properties are mismatched with conventional shells. Less computer-intensive point mass models predict with a high degree of accuracy this same information. Since any user of conventional artillery shells knows in advance the aerodynamic properties of the shell, little, if any, need exists for wind tunnels or finite element fluid modeling. Devices that measure the moments of inertia for many applications other than military purposes are easily adapted for use in measuring artillery shells. Any entity that does not already possess this equipment can purchase it legitimately on the open market.

Reproducing the high accelerations of a gun launch in a laboratory setting is difficult, so experimentalists often resort to subscale tests using small bore cannon or other energy producing devices such as rail guns. A proliferator that wishes to test the response of a new pathogen to high acceleration can use these techniques and then assume that incremental increases in full-scale models follow an extrapolation of the results they have measured.

A proliferator with a slightly more advanced design capability can extend the range of the 155-mm shell to approximately 50 km, either by using base bleed supplemental blowing to shape the aerodynamics over the boat tail or by lengthening the barrel. A lengthened barrel increases the spin rate proportionately and exaggerates all of the problems formerly identified with spinning shells. For use beyond 50 km, the proliferant must manufacture both the gun and the shell. Fifty kilometers is sufficient range for a proliferant to threaten coastal cities or an adversary's territory adjacent to a common border.

The "Foreign Technology Assessment" paragraphs will discuss which countries can develop WMD to fit existing artillery pieces. It also discusses which countries have the technical wherewithal to continue to pursue research into a Supergun.

The tables that follow this text list, in order of priority, technologies that a proliferant needs to produce WMD artillery shells that fit into existing guns and then cover the more stressing task of building a new artillery piece on the scale of the Supergun.

Multiple Launch Rocket System as a Means of Delivery

In many cases, the flight dynamics limitations imposed on the use of WMD with artillery shells can be mitigated by employing a Multiple Launch Rocket System (MLRS). MLRS batteries launch a salvo of missiles against a target from a collection of launch tubes mounted on, or towed by, a highly mobile vehicle. Generally, the delivery systems constituting a MLRS have a range of less than 50 km, but the exact range can be extended depending on the circumstances. Since the MLRS uses a rocket as its basis, the accelerations that a warhead endures at launch are much less than those for an equivalent range artillery shell. Similarly, the rocket uses aerodynamic stability with fins or airframe shape so the warhead is not subjected to the high spin rates that an equivalent range artillery shell needs to maintain gyroscopic stability. Also, the rocket does not travel as fast as an artillery shell, so fuzing and firing operations can be less precise than with an equivalent artillery shell. This long flight time also gives submuntions an opportunity to be dispensed properly.

In the field, the MLRS offers many logistical and tactical advantages for delivering chemical and biological agents. Since the attacker uses the MLRS in a salvo mode, the individual missiles can be launched to cover a large area when they arrive at a target. This could lay down an effective cloud of chemical or biological material, which may deny large areas of a battlefield to a defender. However, care must be taken to ensure that the close proximity of salvo round detonations does not have a negative effect on agent vitality or dispersion. Consequently, this tactic makes MLRS an unlikely choice for nuclear munitions.

Since MLRS systems have widespread applications for anti-personnel, anti-tank, and anti-armor operations, knowledge of their design, manufacture, and use is widely available to many U.S. allies and trading partners. Many derivative versions of the system have been built to accomplish special targeting objectives that have application to the use of WMD. For instance, the Army Tactical Missile System (ATACMS) used with the MLRS uses a special, long-range missile while the anti-tank version deploys a submunition in mid-flight, similar to the deployment that would be required to deliver chemical or biological agents efficiently.

In the U.S. version of the MLRS, which has been widely studied overseas, the rocket can accept a warhead weight of up to 156 kg on a system with a total weight of 306 kg. This is about twice the payload that a 155-mm shell delivers and at a price of about three times the system weight. Hence, the warhead structural efficiency factor is less than that for artillery shells, but the simplicity of the operation more than compensates for the loss of efficiency. An MLRS rocket, as built by the United States, has a diameter of 227 mm and a length of 3.937 m, making it easy to ship, stockpile, and deploy.

The United States has sold MLRS systems that theoretically can be retrofitted for chemical or biological use to many trading partners abroad. A Memorandum of Understanding among the United States, Germany, France, the UK, and Italy allows for joint development, production, and deployment of the United States design. Currently, the United States and others have sold and deployed the MLRS in Bahrain, Denmark, France, Germany, Greece, Israel, Italy, Japan, the Netherlands, Norway, Turkey, the UK, and the United States. Russia and the FSU have several variants of an MLRS in production and service. In fact, in the latter half of the decade, a clear competition has emerged between the United States and the Russians to sell MLRS systems as part of their arms packages. The Russian systems are made by the SPLAV consortium and are called the SMERCH: a 300-mm rocket, the Uragan, a 220-mm system, and the Prima, which is 122 mm in diameter. The Russians also wish to market two other systems, which are both 140 mm in diameter. The Russians have sold the 300-mm Smerch to Kuwait and the United Arab Emirates (UAE), and the Uragan system has been sold to Syria and Afghanistan. Many other variants still exist in the former Eastern Bloc states.

RATIONALE

Artillery shells present the exception to the rule that a proliferant must pursue some technological capability to deliver WMD. Artillery pieces are ubiquitous in any military; thus, armies are fully trained in their use. The United States and the Soviets built a large arsenal of nuclear and chemical shells to fit these existing artillery pieces and designed them so that all of the preparations and firing procedures associated with them closely mirror conventional rounds. The United States is in the process of destroying its chemical shells, but some do exist and many nuclear artillery shells are still in Russia. Consequently, the possibility that a proliferator could find a way to acquire a fully weaponized WMD shell and use it in existing military hardware cannot be ruled out.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 1.5-1)

Since virtually every country in the world with a military has artillery pieces and the training to accompany their use and theory of operation, a proliferant must only manufacture the WMD shells for these guns if it intends to deliver the munitions at ranges less than 50 km. As an alternative, proliferants may clandestinely acquire shells to use in their artillery pieces. The United States, Russia, and, by common belief, Israel have made nuclear shells. The United States, Russia, reportedly France, and possibly Israel have made chemical and biological shells. The United States builds its shells in standard 155- and 203-mm caliber. Most European countries use the same bore. In the Russian tradition, the Soviet Union built its shells in 152- and 202-mm caliber. A shell from these stocks fits and can be fired from the larger bore U.S. and European guns, but the reverse is not true. When the smaller Russian shells are fired from U.S. and European guns, there is a small additional blow by and consequent loss of acceleration to the shell. Even then, care must be taken to ensure that the close proximity of salvo round detonations does not have a negative effect on agent destruction or dispersment; therefore, this configuration produces a slight range loss and additional wobble upon exit from the gun.

The United States, Canada, Sweden, Denmark, Finland, Austria, Norway, Belgium, France, Germany, the Czech Republic, all the Baltic Republics, Ukraine, Belarus, Italy, Spain, Greece, elements of the former Yugoslavia, China, North Korea, South Africa, Israel, Egypt, Cuba, Vietnam, South Korea, Taiwan, Iran, Iraq, Pakistan, India, and Afghanistan have all built artillery pieces or have the infrastructure to build them according to either the U.S. and European standard or the former Soviet one. Most of these countries' military officers have been trained on the weapons and are capable of advising a proliferant on methods to either build the guns or obtain them legitimately from a supplier nation. If a proliferant found itself in possession of a standard WMD artillery shell, any of these countries could supply the gun to fire it for less than $250,000, without even needing to understand the nature of the shell.

A proliferator may decide to manufacture its own gun, particularly if it designs a WMD device employing a gun-assembled, as opposed to an implosion, nuclear weapon. An entry-level, gun-assembled, nuclear weapon requires a gun barrel diameter of approximately 650 mm rather than 155 mm. There are some 16-inch (406-mm) guns in many nations' arsenals, and an innovative gun-assembled nuclear weapon may have a diameter this small. But the 16-inch guns are not as readily available as the 155-mm guns, and a proliferant would generate the attention of export control authorities if it tried to purchase one.

Several proliferants have the technical capacity to build a gun approaching the Supergun if they can find a supplier of specialty steels for the barrel and large action hydraulic cylinders for the recoil mechanisms. The specialty steel tubes must have interior surfaces with deviation in diameter of less than 50 μm per 20 mm of tube diameter and deviation from a true longitudinal axis of less than 1 mm per meter of length. Oil-producing nations that produce their own pipelines, as a rule, have no reason to make tubes that meet the standards of gun barrel manufacture. Pipelines generally carry oil under a pressures of several atmospheres, rather than the several hundred atmospheres that are required for a gun barrel. Moreover, there are no stringent requirements on pipelines for interior surface finish, diametrically, and straightness.

Egypt, Israel, Pakistan, South Korea, and India either have the capability or could quickly obtain the ability to build large bore gun barrels. Many South American nations, in particular Argentina and Brazil, also have the industrial and metallurgical industry to support large bore gun manufacturing.

Country	Weapons Integration			Artillery Place		Aiming and Firing			Propulsion		
	Inertially Matched Shells	High-Energy Burster Charges	Fuzing and Firing Circuits That Withstand Spin and Shock	Barrel Extension for Extended Range	Indigenous Manufac-turing of Gun	Develop-ment of Firing Tables for WMD	Automated Gun Sights Using GPS to Aim	Wind Tunnel and Other Laboratory Equipment to Measure Flow Field	Indigenous Manufac-turing of Large Bore (<400 mm) Guns	Indigenous Manufac-turing of Propelling Charges	Base Bleed Range Extension
Argentina											
Brazil	♦♦♦	♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦♦	♦
Canada	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Chile	♦♦	♦	♦	♦♦	♦	♦♦	♦♦	♦♦	♦	♦♦♦	♦
China	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Egypt											
France	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Germany	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
India	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦	♦♦♦♦	♦♦♦♦
Iran	♦♦♦	♦♦	♦	♦♦	♦♦	♦♦♦	♦♦	♦	♦	♦♦♦	♦♦
Iraq	♦♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦	♦♦♦♦	♦♦♦	♦♦	♦♦♦	♦♦♦	♦♦
Israel	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Italy	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Japan	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Libya	♦♦♦	♦♦	♦♦	♦♦	♦♦	♦♦	♦♦	♦♦	♦♦	♦♦	♦♦
North Korea	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦	♦♦♦	♦♦	♦♦♦	♦♦	♦♦♦♦	♦♦
Pakistan	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦	♦♦♦♦	♦♦	♦♦	♦♦♦	♦♦♦♦	♦♦
Russia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
South Africa	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦
South Korea											
Sweden	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Syria	♦♦	♦♦♦	♦♦	♦	♦	♦♦♦	♦	♦	♦	♦♦♦	♦♦
Taiwan	♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦	♦♦♦♦	♦♦
Ukraine	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦	♦♦♦♦	♦♦♦♦
United Kingdom	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United States	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦

Legend: Sufficient Technologies Capabilities: ♦♦♦♦ exceeds sufficient level ♦♦♦ sufficient level ♦♦ some ♦ limited

Because two or more countries have the same number of diamonds does not mean that their capabilities are the same. An absence of diamonds in countries of concern may indicate an absence of information, not of capability. The absence of a country from this list may indicate an absence of information, not capability.

Figure 1.5-1. Artillery Foreign Technology Assessment Summary

Table 1.5-1. Artillery Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
High capacitance batteries	Resistant to 250 Hz spin rate, and 10,000 g's acceleration, 30V output @ 300 mA	WA Cat. 3A; CCL Cat. 3A	Non-fluid electro-lytes, or fluorboric acid in copper ampules	None Identified	None Identified
Radar altimeters	Resistant to 250 Hz spin rate, and 10,000 g's acceleration	MTCR 11; WA Cat. 7A; CCL Cat. 7A; USML XI	None Identified	None Identified	Altitude calculation cycle time <50 msec
Radio timing fuze	Resistant to 250 Hz spin rate, and 10,000 g's acceleration	WA ML 11; USML XI	None Identified	High-speed data acquisi-tion equipment and computer boards	Timing accuracy <5% of set time for set times of 5 to 150 seconds
Electronic timers (e.g., US M724 electronic fuze)	Resistant to 250 Hz spin rate, and 10,000 g's acceleration	WA ML 11; USML XI	None Identified	High-speed data acquisi-tion equipment and computer boards	Event sequencing capability <5 msec.
Bursters	Resistant to 250 Hz spin rate, and 10,000 g's acceleration	WA ML 11; USML XI	None Identified	None Identified	None Identified
Expelling charges	Resistant to 250 Hz spin rate, and 10,000 g's acceleration	WA ML 11; USML XI	None Identified	None Identified	None Identified
Casing material	Resistant to low level radiation background	CCL Cat. 1	Phenolics	None Identified	None Identified
Dual canister burster charge	Resistant to 250 Hz spin rate, and 10,000 g's acceleration	WA ML 11; USML XI	None Identified	None Identified	None Identified

Table 1.5-2. Artillery Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
High capacitance batteries	Nuclear firing circuits require high energy initiation, which must be contained in a lightweight package to fit on an artillery shell	Reliable detonation	None Identified
Radar altimeters	Altitude must be sensed with sufficient accuracy to release aerosol under the atmospheric shear layer but before ground impact	Chemical or biological weapon detonation	Timing circuits, barometric sensors, acceleration detectors
Radio timing fuze	Range and range rate must be calculated in a moving reference frame	Any airborne conventional, chemical, or biological weapon	Timing circuits, barometric sensors, acceleration detectors
Electronic timers (e.g., US M724 electronic fuze)	Designing electronic circuits with piezoelectric crystals that remain unaffected by high shock loads	Reliable detonation	High-speed data acquisition equipment and computer boards.
Bursters	Bursters must not fire prematurely in high shock environment	Reliable detonation	Any insensitive high explosives
Expelling charges	The expelling charge must decelerate submunitions sufficient so that air brakes or parachutes may be deployed; often this must be done in a short times span and high energy charges may damage biological or chemical agents.	Submunition dispensing	None Identified
Casing material	Embrittlement occurs when some steels are exposed to intrinsic radiation for long periods of time	Applications requiring resistance to nuclear radiation environments	None Identified
Dual canister burster charge	Binary materials are mixed in flight; in order to be mixed, two canisters are usually opened with shaped charges or other HE technology, but the charge can not compromise the chemical or biological agent	Binary chemical munitions	None Identified